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Environmental Impact of Highway Deicing

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27 Abstract Deicing agents for removal of ice and snow from highways and streets are essential to wintertime road maintenance in most areas of the U.S. Due to the ever-increasing use of highway deicing materials, there has been growing concern as to environmental effects resulting from these practices. This State-of-the-Art report critically reviews the available information on methods, equipment and materials used for snow and ice removal; chlorides found in rainfall and municipal sewage during the winter; salt runoff from streets and highways; deicing compounds found in surface streams, public water supplies, groundwater, farm ponds and lakes; special additives incorporated into deicing agents; vehicular corrosion and deterioration of highway structures and pavements; and effects on roadside soils, vegetation and trees. ~~It is concluded that~~ highway deicing can cause injury and damage across a wide environmental spectrum. Recommendations describe future research, development and demonstration efforts necessary to assess and reduce the adverse impact of highway deicing. ~~This report was prepared by the Storm and Combined Sewer Pollution Control Section, Edison Water Quality Laboratory, Water Quality Research of the Environmental Protection Agency.~~ (Struzeski - EPA)			
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Environmental Impact of Highway Deicing

ENVIRONMENTAL PROTECTION AGENCY
WATER QUALITY RESEARCH

Edison Water Quality Laboratory
Storm and Combined Sewer Overflows Section, R&D
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ABSTRACT

Deicing agents for removal of ice and snow from highways and streets are essential to wintertime road maintenance in most areas of the U.S. Due to the ever-increasing use of highway deicing materials, there has been growing concern as to environmental effects resulting from these practices. This state-of-the-art report critically reviews the available information on methods, equipment and materials used for snow and ice removal; chlorides found in rainfall and municipal sewage during the winter; salt runoff from streets and highways; deicing compounds found in surface streams, public water supplies, groundwater, farm ponds and lakes; special additives incorporated into deicing agents; vehicular corrosion and deterioration of highway structures and pavements; and effects on roadside soils, vegetation and trees. It is concluded that highway deicing can cause injury and damage across a wide environmental spectrum. Recommendations describe future research, development and demonstration efforts necessary to assess and reduce the adverse impact of highway deicing. This report was prepared by the Storm and Combined Sewer Pollution Control Section, Edison Water Quality Laboratory, Water Quality Office of the Environmental Protection Agency.

KEY WORDS: Additives, concrete deterioration, environmental damages, groundwater contamination, highway deicing, plant tolerances, public water supplies, salt storage, vehicular corrosion, water pollution effects, wintertime highway runoff.

Резюме

Противообледенительные средства для удаления льда и снега с дорог и улиц существенно для поддержки дорог в зимнее время в большинстве районов Соединенных Штатов. Из-за постоянно увеличивающегося применения противообледенительных материалов на дорогах, стали возникать заботы о последствиях для окружающего мира вытекающих из этой практики. В этом докладе критически рассматриваются опубликованные сведения о способах, оборудовании и материалах применяющихся при удалении снега и льда; о хлоридах находящихся зимой в дождевой воде и в городских стоках; о соляном стоке с улиц и дорог; о противообледенительных соединениях найденных в наземных потоках, городских водоснабжениях, грунтовой воде, придорожных прудах и озерах; о специальных присадках внедренных в противообледенительные средства; о коррозии повозок и ухудшении дорожных покрытий и мостовых; и о влиянии на придорожную почву, растительность и деревья. Приходят к заключению что обезлеживание дорог может причинить повреждения и вред в широком диапазоне спектра окружающего мира. В рекомендациях даются описания исследований, разработок и удостоверений необходимых в будущем для оценки и снижения неблагоприятного действия обезлеживания дорог. Этот доклад был составлен Отделением по контролю загрязнения дождевых и смешанных сточных вод Лаборатории имени Эдисона для определения качества воды при водосточном качестве воды Управления защиты окружающего мира.

Категории: Присадки, ухудшение бетона, повреждения окружающего мира, загрязнение грунтовой воды, обезлеживание дорог, границы выносливости растений, городские водоснабжения, хранение соли, коррозия повозок, последствия загрязнения вод, зимние дорожные стоки.

Auszug

Enteisungsmittel zur Beseitigung von Eis und Schnee von Landstrassen und Strassen sind für die Strassenunterhaltung im Winter in den meisten Bezirken der Vereinigten Staaten wesentlich. Infolge des immer grösser werdenden Gebrauches von Strassen enteisungsmitteln, wurde man immer mehr um die daraus entspringenden Einflüsse auf die Umwelt besorgt. Dieser Bericht betrachtet kritisch die gegenwärtigen Kenntnisse von den Methoden, Geräten und Materialien die zur Beseitigung von Schnee und Eis benutzt werden; von Chloriden die sich im Winter im Regenwasser und in städtischen Abwässern vorfinden; vom Salzabfluss von Strassen und Landstrassen; von Enteisungsverbindungen die sich in Oberflächenwasser laufen, im Wasser von öffentlichen Wasserverteilungsanlagen, in Gehäusen teichen und in Seen vorfinden; von den Son derzusatzmitteln die in der Enteisungsmitteln einverleibt werden; von der Korrosion von Fahrzeugen und der allmähliche Zerstörung von Strassenbauwerken und -pflastern; und von den Wirkungen auf den Erdboden, die Pflanzen und die Blume an den Landstrassenrändern. Man kommt zu dem Schluss dass die Landstrassenenteisung es vermag Verletzungen und Schäden in einen breiten Band des Umweltspektrums zu verursachen. Empfehlungen betreffen zukünftige Forschungs- und Entwicklungstätigkeit sowie Versuchsmassnahmen die erforderlich sind um den ungünstigen Einfluss der Landstrassenenteisung auszuwerten und zu vermindern. Dieser Bericht wurde von der Abteilung für Verunreinigungskontrolle von Regenwasser- und Mischkanalisation des Edison Wasseruntersuchungslaboratoriums des Wasserqualitätsamtes der Umweltschutzverwaltung.

Schlüsselworte: Zusatzmittel, Betonzerstörung, Umweltschaden, Grundwasser-
verunreinigung, Landstrassenenteisung, Pflanzentoleranzen,
Öffentliche Wasserversorgungsanlagen, Salzlagerung,
Fahrzeugkorrosion, Auswirkungen der Wasserverunreinigung,
Landstrassenwasserablauf im Winter.

Résumé

Les agents dégivrants pour l'enlèvement de la glace et la neige des chemins et des rues sont essentiels à l'entretien des voies en hiver dans la plupart des régions des États Unis. Du à l'utilisation toujours plus répandue des matériaux dégivrants pour les chemins, un souci s'éleva concernant les effets environnementaux résultant de cette technique. Cet rapport de présente une revue critique de l'information disponible sur les méthodes, l'outillage et les matériaux employés pour l'enlèvement de la glace et la neige; sur les chlorures qui se trouvent dans l'eau de pluie et les eaux d'égouts municipales en hiver; sur le découlement du sel des rues et des chemins; sur les composés dégivrants qui se trouvent dans les fleuves superficiels, les approvisionnements d'eau publics; les eaux souterraines, les abreuvoirs et les lacs; sur des additifs spéciaux incorporés aux agents dégivrants; sur la corrosion vehiculaire et la détérioration des structures et des pariments des chemins; et sur l'effets sur les sols, la végétations et les arbres situés au bord des voies. On conclut que la dégivration des chemins peut faire du tort et du dommage au travers une bande épandue du spectre environnemental. Les recommandations décrivent les efforts futurs de recherche, de développement et de démonstration qui seront nécessaires à évaluer et à réduire l'impact adverse de la dégivration des chemins. Cet rapport fut préparé par la Section de Contrôle de la pollution des égouts d'eau de pluie et des égouts mixtes de la Laboratoire Edison pour détermination de la qualité d'eau du Bureau de Qualité d'eau de l'Administration de Protection environnementale.

Mots clef: Additifs, détérioration du béton, dommages environnementaux, contamination des eaux souterraines, dégivration des chemins, tolérances des plantes, approvisionnements d'eau publics, magasins du sel, corrosion vehiculaire, effets de la pollution d'eau, decoulement des chemins en hiver.

Resumen

Agentes descongelantes para la eliminación de hielo y nieve de las calles y carreteras son esenciales para el mantenimiento de las vías de comunicación en la mayor parte de los Estados Unidos durante el invierno. Debido al aumento constante de materiales descongelantes en las carreteras existe una creciente preocupación en cuanto a los efectos surgidos como resultado de estas prácticas en el medio ambiente. Este informe de estado-del-arte revisa críticamente la información existente sobre métodos, equipos y materiales usados para la remoción o eliminación de nieve y hielo; cloro encontrado en depósitos de lluvia y desagües municipales durante el invierno; sal derramada en las carreteras y calles; compuestos de materiales descongelantes encontrados en la superficie de arroyos, de abastecimientos de aguas públicas, aguas subterráneas, estanques de granjas y lagos, agregados especiales incorporados a los agentes descongelantes, corrosión de vehículos y deterioración de estructuras de las carreteras y pavimentos; y sus usos sobre el terreno contiguo a las mismas, su vegetación y arboleda. Como conclusión se ha determinado que la descongelación de carreteras puede causar grandes daños y perjuicios a una gran parte del medio ambiente. Las recomendaciones describen investigaciones a realizarse en el futuro, explicando y demostrando los esfuerzos necesarios requeridos para estimar y reducir los impactos adversos en el descongelamiento de carreteras. Este informe fue preparado por la Sección de Control Combinado de Tormentas y Polución de Cloacas en el Laboratorio Edison para la Calidad del Agua, Oficina de Calidad del Agua de la Agencia de Protección del Medio Ambiente.

Palabras Claves: Agregados, Deterioración del Cemento, Daños al Medio Ambiente Contaminación de Aguas Subterráneas, Descongelamiento de Carreteras, Tolerancia de Plantas, Abastecimiento de Aguas Públicas, Reservas de Sal, Corrosión de Vehículos, Efectos de Polución en el agua, Derrames en las Carreteras durante el invierno.

RESUMO

Agentes para o degelamento, na remoção do gelo e da neve das auto-estradas e ruas, são essenciais para a manutenção das vias de comunicação na maior parte dos Estados Unidos, durante o inverno. Devido ao constante aumento no uso de materiais degelantes nas estradas tem havido uma crescente preocupação quanto aos efeitos resultantes destas práticas ao meio ambiente. Este relatório do estado-da-arte revisa criticamente a informação existente sobre os métodos, equipamento e materiais usados para a remoção de neve e de gelo; chlorureto encontrado em depósitos de chuva e esgotos municipais durante o inverno; sal escoado das ruas e estradas; compostos de materiais degelantes encontrados na superfície de rios, em abastecimento de águas públicas, águas subterrâneas, estanques de fazendas e lagos; aditivos especiais incorporados aos agentes degelantes; corrosão de veículos e deterioramento das estruturas e pavimentação de estradas; e efeitos nos solos próximos as estradas; na vegetação e árvores. Foi concluído que o degelamento de estradas pode causar danos e prejuízos à uma larga faixa do meio ambiente. As recomendações descrevem as pesquisas para o futuro, fazem uma explanação e demonstração dos esforços necessários para a determinação e a redução do impacto adverso no degelamento de estradas. Este relatório foi preparado pela Seção de Controle Combinado das Tempestades e da Poluição de Esgotos, Laboratório Edison para a Qualidade da Água, Escritório da Qualidade da Água da Agência de Proteção ao Meio Ambiente.

Palavras chaves: Aditivos, deterioramento do cimento, danos ao meio ambiente, contaminação das águas subterrâneas, degelamento de estradas, tolerância de plantas, abastecimento de águas públicas, reservas de sal, corrosão de veículos, efeitos da poluição da água, escoamento das estradas no inverno.

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FOREWORD

Under provisions of the Federal Water Pollution Control Act, as amended, the Office of Water Quality Research in the Office of Research and Monitoring within the Environmental Protection Agency, is authorized to conduct various basic and applied research; and to develop and demonstrate the results of this research. These activities are undertaken through in-house efforts of the EPA Laboratories, or accomplished through various grants and contracts funded and sponsored by the Office of Water Quality Research -- Research, Development and Demonstration Program.

This report, Environmental Impact of Highway Deicing, has been prepared by the staff of the Office of Water Quality Research -- Storm and Combined Sewer Pollution Control Branch, and represents a significant effort in compilation of broad-base information available in the subject area and assessment of the full impact of highway deicing practices on the environment. This program of the Division of Applied Science and Technology in the Office of Water Quality Research, has continuing active interest in highway deicing because of its inherent responsibilities in the evaluation, control and treatment of waste overflows from combined sewers and discharges of sewerage and non-sewerage urban runoff. Because of serious pollution existing in many receiving streams in this country, and the increasing public awareness of these ever important problems, it is appropriate that the environmental issues concerned with highway deicing be reviewed and examined in much greater depth.

The use of deicing salts and other materials for removal of ice and snow from highways, roads and streets, is essential to wintertime road maintenance operations in most areas of the U.S. This report is mainly derived from a detailed review of the literature, and from contacts with various groups and individuals knowledgeable of the potential and real consequences of highway deicing. This report focuses on the characteristics of snowmelt runoff and the effects of highway deicers and their associated additives upon surface streams, rivers, lakes, ponds, groundwaters, private, public and industrial water supplies. The report also describes snow removal operations, chlorides in rainfall, the effects of deicing salts upon wildlife, roadside vegetation, and the corrosion of vehicles and highway structures caused by highway salts.

Several research projects in the past have studied alternative deicers in place of the chloride salts, and various non-chemical methods for removing ice and snow from roads and highways. None of these materials and methods in contrast to the sodium and calcium chloride salts, are apparently considered economical or reliable for widespread use.

Except for a) limited research by State highway departments and possibly by the Federal Aviation Authority; b) investigations nearly completed by the Virginia Polytechnic Institute for the U.S. Highway Research Board; and c) recent completion of corrosion studies by the American Public Works Association, there is no known large-scale research being

carried forth at the present time on highway deicing and its environmental effects. The majority of results from the VPI-HRB study have been previously made available. National Cooperative Highway Research Program Report 91 by VPI and HRB published in 1970, contains considerable information on the subject of highway deicing and constitutes an important reference used by this EPA study.

Suggestions and recommendations are given in identifying present research and development needs toward alleviation of detrimental effects caused by highway deicing. This report should also serve to outline and describe procedures that may be necessary for complying with current Federal regulations on environmental protection during the design phase of highway projects. The National Environmental Policy Act of 1969, Executive Order 11514 on "Protection and Enhancement of Environmental Quality," and the Highway Act of 1970 make provisions for determining environmental impact of major Federal actions including all Federal-aid highway projects. Adherence to these provisions could involve various aspects such as calculating salt runoff concentrations and loads; modification of existing surface drainage; suitability of roadside plantings and vegetation cover; the fate and disposition of salt runoff after leaving the highway surface; and the possible need for runoff treatment.

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SECTION I

CONCLUSIONS

1. Review of the literature, and numerous contacts with groups and individuals knowledgeable of highway deicing operations and the associated consequences, indicate that highway salts can cause injury and damage across a wide environmental spectrum. Furthermore, it is believed that many of these effects although not yet evident in certain areas of the country, may well appear in the near future. Effects of highway deicing appear most significant in causing contamination and damage of groundwaters, public water supplies, roadside wells, farm supply ponds, and roadside soils, vegetation and trees. Deicers also contribute to deterioration of highway structures and pavements, and to accelerated corrosion of vehicles.
2. Sodium chloride and calcium chloride are used almost exclusively as deicing agents because of their efficiency in melting ice and snow, availability, and relatively low material cost. Most deicing salts are now applied "straight" onto streets and highways. In 1947, less than one half million tons of deicing salts were used in the U.S. Annual use of these salts increased to around 9 million tons in 1970, and by 1975, annual use is expected to approach 12 million tons. Quantities of sand, cinders and other abrasives for wintertime road maintenance have decreased considerably in recent years. Chemicals are fast-acting whereas abrasives attack the problem only after ice and snow are formed.
3. Practically all highway authorities in the U.S. firmly believe that ice and snow must be removed as quickly as possible from roads and highways, and that "bare pavement" conditions are essential to protect the lives and safety of motorists using these roads. This policy is also considered proper in minimizing disruption of normal business, commercial and public activities and services which could be seriously affected by adverse winter conditions. Maintaining bare pavement conditions does, however, require frequent and liberal applications of road deicers and/or more precise spreading.
4. Road salts are usually applied at rates of 400 to 1,200 pounds of salt per mile of highway per application. Over the winter season, many roads and streets may receive more than 20 tons of deicers per lane mile, which is equivalent to 100 tons salt or more applied per mile of roadway for multiple-lane highways. In using highway deicers, it is not necessary to melt more than 10 percent of the ice cover and possibly much less. Vehicular traffic will normally melt the remaining ice and snow quickly and efficiently.

Excessive application, misdirected spreading and wasting of road salts occur frequently. Improved spreading practices if equated in

terms of direct annual cost savings, may possibly amount to several million dollars Nationwide without sacrificing the quality of winter-time road maintenance.

5. Materials storage sites are a frequent source of salt pollution to groundwaters and surface streams. Deicing salts are often stockpiled in open areas without suitable protection against inclement weather. Salt-laden drainage often has direct access to nearby water supplies. Careful site selection and properly-designed materials storage facilities would serve to minimize incidents of water supply contamination and provide for better product handling and quality control. In certain cases, diversion and interception of salt drainage are indicated, and treatment of these flows may also be required.
6. The special additives found in most road deicers cause considerable concern because of their severe latent toxic properties and other potential side effects. Significantly, little is known as to their fate and disposition, and effects upon the environment. The complex cyanides used as anti-caking agents and the chromate compounds used as corrosion inhibitors have been found in public water supplies, groundwaters, and in storm and combined sewer flows. Unusually small amounts of cyanide and chromium are sufficient to cause rejection of public water supplies and cause death of fish and associated aquatic organisms. The phosphate additives also used for corrosion control, may contribute significantly to nutrient enrichment in lakes, ponds and streams leading to algal blooms and noxious conditions.

Recent information supplied by the salt industry cites reduction in the amounts of sodium ferrocyanide added to highway salts and furthermore, that sale of chromium-treated salts was stopped in early 1971 by the largest supplier in the field. These changes are not considered sufficient to modify the recommendations in this report concerning deicer additives. These measures are viewed in terms of the potentially serious nature of both cyanide and chromium additives, the continuing importance of these compounds, and the absence of field data on the fate, disposition and persistence of these materials in the environment.

7. A sufficient number of incidents and detailed studies have been described to show the adverse impact and significant damages caused by deicing salts to groundwaters, public water supplies, household supplies, farm ponds, lakes and small streams. Use of deicing salts has caused many wells and groundwater supplies to be abandoned or replaced. In less severe cases of salt intrusion into public water supplies, salt-free patients have been cautioned to make certain changes, possibly converting to use of bottled water. Unfortunately, rectification of a contaminated groundwater aquifer generally requires many years after remedial measures are first initiated.

8. Road deicing salts are found in high concentrations in highway runoff. Large salt loads enter municipal sewage treatment plants and surface streams via combined and storm sewers, and direct runoff. Concentrations of chlorides as high as 25,000 milligrams per liter (mg/l) have been found in street drainage, and up to 2,720 mg/l in storm sewers. Surface streams along highways and those in urban areas have been found to contain up to 2,730 mg/l chlorides. Influence of highway salts upon major rivers in the U.S. at this time appears relatively minor. Nevertheless, it is recognized that there is inadequate surveillance data to clearly define this area and more information is necessary.

Earlier reports in the literature inferred for highway salt application, that approximately one-half of these salts would be readily flushed into the surface runoff and receiving streams, whereby the remaining salts would be generally retained in the local area. However, recent studies carried forth in Chicago, Syracuse and northeastern Vermont, indicate that most if not nearly all this salt load given sufficient time, in certain cases, may find its way into downstream waters. Both the Syracuse and Vermont investigations noted that these loads were being contributed to street sewers and surface streams throughout the year, and were adding significant salt to stream baseflows particularly in the summertime. Additional studies providing material salt balances for selected watersheds, are considered important in better understanding hydrological influences in the overall transport of these deicing salts.

9. Much of the general literature is somewhat inconclusive on vehicular corrosion and deterioration of highway structures and pavements caused by deicing salts. Some of the more recent reports however are more definitive.

The majority of in-depth studies support the conclusion that deicing salts are a major cause of vehicular corrosion. Likewise it is concluded from the literature that rust inhibiting additives do not produce results which would justify their continued use. Frequent car washing is likely the best protection possible.

Concrete pavements and concrete bridge floors and decks show least resistance to attack by road deicers. It probably would be best never to apply road salts to concrete surfaces but a compromise is necessary between deicing, progressive surface deterioration, protective treatments, and preventive and corrective maintenance.

It is also recognized that deicers may attack and cause damage to telephone cables, water distribution lines, and other utilities adjacent to streets and highways.

10. There is no doubt that highway deicers can seriously disturb a healthy balance in soils, trees, and other vegetation comprising the roadside environment. Total soluble salts, and sodium and

chloride ions reduce soil fertility and structure, depress plant water uptake, and are toxic to plants and vegetation above certain limits. Total soluble salt increases in soils have been noted up to 100 feet from previously salted highways, and progressive accumulation of salts in the roadside area has been verified. The state of health of vegetation, or conversely the degree of damage to vegetation, may be correlated with chloride and sodium levels in plants and soils. Salt tolerance varies considerably between different plant species and is an important criteria in properly selecting vegetation along new highways. Following severe damage by salts, extensive corrective measures may be indicated.

SECTION II

RECOMMENDATIONS

Based on Conclusions detailed in Section I of the report, it is recommended that:

1. A Deicer Users Manual be developed describing snow and ice removal practices and the best systems of applying deicing chemicals to streets and highways. Several highway agencies and the salt industry are known to have various instructional materials which are principally directed to operational performance. The best data in this area should be incorporated into the Manual. Pollution of the surrounding environment and potential in cost savings do not warrant excessive salting, and the Deicer Users Manual should give utmost priority to environmental protection. The Manual should include but not be restricted to:
 - a) Absolute minimum amounts of deicing chemicals necessary to maintain safe traffic flows;
 - b) Critical points or places of application;
 - c) Higher degree of instrumentation, improved calibration, and increased reliability of existing and new deicing equipment;
 - d) Proper maintenance and repair schedules;
 - e) Methods of salt spreading to optimize operational and manpower efficiencies;
 - f) Means for rating materials and methods;
 - g) Development of suggested prime systems and alternatives;
 - h) Incorporation of European and British practices as they may apply in the United States.
2. A Manual of Design and Recommended Practice be prepared for storage facilities and methods of handling deicing materials throughout storage. Although certain instructional materials are available from highway agencies and the salt industry on proper salt storage, there has not been an adequate acceptance of approved practices and a proper recognition of pollution problems associated with materials storage. Many storage sites are located on marginal lands adjacent to streams and rivers, deicing materials are often stockpiled unprotected in open areas, and too frequently these sites have become chronic sources of ground and surface water pollution.

As a minimum, the Manual of Design and Recommended Practice should describe:

- a) Proper siting of materials storage to eliminate pollution;
 - b) Adequate covering of storage sites to protect materials and preclude surface drainage;
 - c) Suggested design of storage facilities, particularly enclosed structures;
 - d) Adequate foundation and footings;
 - e) Desirable sequence and timing of materials delivery;
 - f) Best methods for handling and moving products to and from, and within the storage facility;
 - g) Suggested precautions in placing, mixing, treating and withdrawing materials to reduce product waste and damage;
 - h) Materials quality control methods;
 - i) Minimum supervision requirements for the various operational phases;
 - j) Suggested minimum codes for deicing materials storage to be adhered to by Federal, State, county, local and other authorities responsible for wintertime road maintenance.
3. Increased recognition of environmental pollution problems caused by highway deicing be fostered at Federal, State, county, and local levels. This recognition should include program development and funding so as to provide for greatly increased training, environmental impact awareness, and demonstration of optimum procedures and techniques necessary in wintertime highway deicing. This concerted effort in training and education should be primarily directed to highway department personnel at the working levels, and it is believed this program would be most appropriately and effectively carried forth by the State highway departments and their designees. Training support by the industry should improve such programs.
4. Detailed investigations be conducted both in the laboratory and field on the various additives mixed with deicing materials to determine their potential hazards, and safe levels of use. In view of the limited amount of data available on deicing additives and toxic nature of some additives, proper justification on the continuing use of these products is sought. This should include comparative merits of substituting and/or developing other additives,

or none at all. These studies should additionally cover but not be restricted to:

- a) Collection and analysis of data obtained from continuous monitoring of selected deicing storage and application areas.
 - b) Basic research particularly on the cyanide and chromium additives, with regard to chemical reactions and pathways; environmental interferences; and direction, movement, persistence and degradation of additives through soil, vegetation and water.
 - c) Relationship of present water and air quality use criteria to those levels of additives expected to be found in water, air and soils.
 - d) Development of a comparative test for rating the toxicity level and potential hazards of various additives.
 - e) Determination if purposes intended by product use are being met.
5. Consideration be given to initiating a program designed to obtain base-line data on long-term environmental changes that may be taking place due to the increasing use of deicing chemicals. Such a program would denote need for preventive and corrective measures before severe and irreversible damage to our natural resources occurs. Program implementation would require support from State, county and local water resource agencies, and various highway authorities, as well as the Federal government. The program should provide continuous data for:
- a) Levels of deicing chemicals present in surface waters, groundwaters including recharge areas, and in highway runoff;
 - b) Levels of deicing chemicals found in selected soils and vegetation;
 - c) Corrosion levels prevailing for selected vehicles, highway bridges, pavements, buildings, etc., correlated with known uses of deicing chemicals;
 - d) Presence of deicing ions in other critical areas as future needs indicate.
6. Federal, State and local highway authorities give appropriate consideration in highway design to road deicing and the control, collection and treatment of ensuing salt runoff. Where intensive deicing operations warrant, initial plans may include rerouting

new highways to minimize adverse effects upon roadside resources, and providing for accelerated runoff away from susceptible soils, grasses and trees. Broader implementation of salt runoff control may involve extensive drainage, alteration of existing drainage patterns, diversion canals, underground pipelines, and various ponds and lakes. Conveyance and storage units should be aesthetically blended into the roadside landscape. Collected drainage utilizing flow regulation, may possibly be released safely downstream. Otherwise, terminal point storage or treatment of this drainage may be necessary.

In control and treatment of highway runoff, it may be advantageous to separate the concentrated salt flows from dilute flows. Recycling of salt flows and recovery of salts by evaporation or other means may be proved feasible. Treatment of these flows would be enhanced by research, development and demonstration of alternative concepts and methods.

7. Information be compiled and disseminated on best selection of roadside plantings, and remedial measures for restoring roadside vegetation damaged by deicing chemicals. Plantings should be generally chosen on the basis of maximum salt tolerance, but trade-offs are indicated with respect to shape and contour of the land, protection of other resources, existing plantings, local climate, State highway codes, availability of highway maintenance funds, etc.

Damage of natural or implanted growth in roadside areas is frequently followed by accelerated erosion of side slopes, loss of aesthetics, and severe sedimentation of nearby streams. Treatment of soils by gypsum and lime, and treatment of foliage by certain liquid sprays, are indicated as being practicable for restoring roadside vegetation where deicing chemicals have stunted natural growth, reduced soil fertility or created toxic conditions in vegetation. Review of remedial methods presently available is considered highly appropriate. New methods should be developed by additional research and demonstration. In cases of severe damage, greater use of artificial materials and functional settings may be possible.

8. Continued practices of removing and dumping the enormous quantities of snow from streets and highways into nearby water bodies or onto water supply watersheds be fully evaluated, particularly in terms of unit pollutant loads and various effects imposed upon these receiving streams. These snow and ice accumulations have been shown to contain high content of chlorides, oils and metallic lead due to road deicing, vehicular traffic and other urban wastes. This problem has received scant attention, and only recently have these snow deposits been cited as a significant contributing source of roadway pollution. There is immediate need for both monitoring and case study data in order to determine the extent and severity of this problem. Such results should serve to define possible requirements

in modifying current snow dumping practices and developing safer means of ultimate snow disposal.

9. The various suppliers and highway authorities make available full information on marine salts - their current and future expected use in highway deicing, chemical composition, physical properties including melting efficiencies, and comparison with the common chloride salts. Marine salts may be different in composition and have even greater polluttional consequences compared to the mined sodium chloride salts. Further evaluation of the environmental impact of marine salts should be made after background data are available.
10. Results, findings and recommendations of past studies dealing with corrosion of automobiles and deterioration of highway structures and pavements potentially caused by road deicers, be made readily available to outside users. Timely presentation of pertinent findings should be given in the widely-used technical journals. Considerable data is believed to exist on deicer-caused damage to structures and vehicles, which if made available, may suffice most needs in this area. Continuing evaluation is nevertheless required.
11. Highway authorities and the suppliers of deicing materials investigate and make available their full results and experience on the merits and demerits of various substitute materials that could be used in place of the common chloride salts. A major objective is to identify those highway deicers having high efficiency and demonstrated minimum side effects. Can current products be modified for greater deicing efficiency, less damage, or even beneficial impact? Would lesser known products compete successfully if they were produced in much larger quantities? It is intended under this recommendation that similar data would be made available on those deicers presently used for ice control around airports and around the home.

The various agencies, users and suppliers of highway deicers should thoroughly investigate previous methods that have shown potential promise, and likewise research and development of new concepts of snow and ice removal should be accelerated. Increased use of abrasives may be indicated for various conditions supported by economic comparison studies. Dark materials which could potentially absorb more solar energy when spread onto streets and highways, merit attention. Greater use of rubberized snow plows, air jet snow throwers, and substitution of studded tires by polyurethane tire chains represent some of the ideas coming on scene today. New concept development would seem to hold reasonably high promise as alternative methods of the future.

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SECTION III

SNOW AND ICE REMOVAL-MATERIALS AND OPERATIONS

Deicing Materials-Bare Pavement Policy

Each winter across this country, highway snow removal and deicing operations begin anew. Chemicals and deicing materials for highway maintenance over the winter of 1966-1967 approximated 6.3 million tons of sodium chloride, 0.25 million tons of calcium chloride, and 8.4 million tons of abrasives. Requirements for Canadian highways over this same period were estimated as 1.1 million tons sodium chloride, 18,000 tons calcium chloride and 3.4 million tons of abrasives(1).

Looking ahead we can expect a substantial increase in over-all use of highway deicers. For sodium chloride alone, deicing use in the United States is estimated around 9 million tons for the past winter of 1970-1971. Projected annual use for 1975 is 11 to 12 million tons(2,3). The twenty-one States in the eastern and north-central sectors of the United States use more than 90 percent of all sodium chloride and calcium chloride sold as highway deicers across the country. The eastern States also are heavy users of abrasives, consuming more than 70 percent of the U.S. total, whereas the north-central States and western States, respectively, utilize about 10 percent and 12 percent of this total. Data are presented in Table I giving reported amounts of sodium chloride, calcium chloride and abrasive materials deployed for highway deicing by individual States and Regions during the winter of 1966-1967.

We may well ask why are the chloride salts preferred for highway deicing and why are such enormous quantities necessary? Winter highway maintenance is a complex problem involving large amounts of resources, manpower and materials at considerable cost. In 1964, the Highway Research Board reported that the cost of snow and ice removal in the 33 snow-belt States was \$151 million, or 8 percent of all highway maintenance costs in that year for those States. Recent costs are undoubtedly much higher. Snow removal is a vital function for many towns and cities and may cost the municipality from 25-50 percent of its entire street maintenance budget(2).

Until the 1960's, highway maintenance departments principally relied on the use of abrasives such as cinders, sand, washed stone and slag screenings for snow and ice control. Abrasives are intended to embed into the snow and ice surface and to provide increased traction and skid prevention. Unfortunately abrasives compared to chemical deicers are less efficient in melting snow and ice (aided by highway traffic); may easily be blown off the road by wind and traffic conditions; require greater application time; and are more costly both in their application and cleanup. At the end of the winter, large amounts of abrasives must be retrieved from shoulder areas, catch basins, and conduits in order to establish proper road drainage(4).

TABLE I

REPORTED USE (TONS) OF SODIUM CHLORIDE, CALCIUM CHLORIDE
AND ABRASIVES BY STATES AND REGIONS IN THE UNITED STATES,
WINTER OF 1966-1967^{a,b/}

<u>STATE</u>	<u>SODIUM CHLORIDE</u>	<u>CALCIUM CHLORIDE</u>	<u>ABRASIVES</u>
<u>EASTERN STATES</u>			
Maine	99,000	1,000	324,000
New Hampshire	118,000	-	26,000
Vermont	89,000	1,000	89,000
Massachusetts	190,000	6,000	423,000
Connecticut	101,000	3,000	335,000
Rhode Island	47,000	1,000	86,000
New York	472,000	5,000	1,694,000
Pennsylvania	592,000	45,000	1,162,000
New Jersey	51,000	6,000	70,000
Delaware	7,000	1,000	2,000
Maryland	132,000	1,000	40,000
Virginia	77,000	22,000	204,000
	1,975,000	92,000	4,455,000
<u>NORTH-CENTRAL STATES</u>			
Ohio	511,000	12,000	43,000
West Virginia	55,000	9,000	230,000
Kentucky	60,000	1,000	-
Indiana	237,000	6,000	77,000
Illinois	249,000	10,000	60,000
Michigan	409,000	7,000	6,000
Wisconsin	225,000	3,000	102,000
Minnesota	398,000	14,000	84,000
North Dakota	2,000	1,000	13,000
	2,146,000	63,000	615,000
<u>SOUTHERN STATES</u>			
Arkansas	1,000	-	-
Tennessee	-	-	-
North Carolina	17,000	2,000	75,000
Mississippi	-	-	-
Alabama	-	-	-
Georgia	-	-	-
South Carolina	-	-	-
Louisiana	-	-	-
Florida	-	-	-
	18,000	2,000	75,000

TABLE I (Cont'd.)

<u>STATE</u>	<u>SODIUM CHLORIDE</u>	<u>CALCIUM CHLORIDE</u>	<u>ABRASIVES</u>
<u>WEST-CENTRAL STATES</u>			
Iowa	54,000	2,000	68,000
Missouri	34,000	3,000	-
Kansas	25,000	2,000	31,000
South Dakota	2,000	1,000	36,000
Nebraska	10,000	-	6,000
Colorado	7,000	-	150,000
	132,000	8,000	291,000
<u>SOUTHWEST STATES</u>			
Oklahoma	7,000	-	2,000
New Mexico	7,000	-	-
Texas	3,000	-	1,000
	17,000	-	3,000
<u>WESTERN STATES</u>			
Washington	2,000	-	155,000
Idaho	1,000	-	47,000
Montana	4,000	-	80,000
Oregon	1,000	-	200,000
Wyoming	1,000	-	43,000
California	11,000	-	94,000
Nevada	4,000	-	50,000
Utah	28,000	-	56,000
Arizona	-	-	-
	52,000	-	725,000
District of Columbia	36,000	-	-
1966-1967 REPORTED TOTALS ^{c/}	4,376,000	165,000	6,164,000

a/ Data taken from Salt Institute 1966-1967 Survey for U.S. and Canada(1).

b/ Represents data by all governmental authorities reporting within each State.

c/ Overall values given in Table I represent about 75 percent of true values (reported and unreported) of salts and abrasives used in 1966-1967. With confidential data and appropriate adjustments, the Salt Institute estimates that U.S. total consumption for the winter 1966-1967 was 6,320,000 tons sodium chloride, 247,000 tons calcium chloride, and 8,400,000 tons abrasives.

The demand that roads be safe and usable at all times, and that June driving conditions be provided in January, has in recent years led to adoption of a "bare pavement" policy by practically all highway departments in the snow belt region. This has required greatly increased use of deicing salts, in many cases replacing the abrasives previously used. Chemical deicers directly attack and melt the ice and packed snow surfaces. As the salt dissolves and melts the upper ice, the resulting brine solution penetrates through the ice and most importantly, causes a break in the tight bonding of ice to the pavement. Chemicals also prevent the formation of new ice.

In 1947, less than one-half million tons of salts were deployed throughout the U.S. for highway deicing, and most of this was admixed with sand and cinders to keep the abrasives from freezing and to facilitate materials handling(2,5). Today, the very large majority of sodium chloride and calcium chloride is applied "straight" onto highways and total amounts exceed 9 million tons annually.

Various chemical deicers are commercially available including rock salt, calcium chloride, and other chlorides, the common ammonium salts, various alcohols, glycerol, and special composition products(6,7,8). Potentially any material which readily mixes with water and lowers the freezing point of water may be appropriate for melting ice and snow. Some deicers produce excess heat which serves as an advantage. Availability, cost and efficiency are considered main criteria in selecting a deicer, and because of these factors, sodium and calcium chloride are used almost exclusively for highway ice and snow control. Of the chloride salts used, sodium chloride represents about 95 percent and calcium chloride 5 percent.

It is the firm philosophy of highway authorities in the U.S. that bare pavement conditions are essential to adequately guarantee the safety and lives of motorists using these roads and highways. Highway officials state that savings from the use of highway salts cannot be adequately measured. For example, it can never be known the number of lives saved, the number of personal injuries avoided, and how much automobile and property damage is averted by substituting bare pavement for ice and snow packed roads. It is generally true that little sympathy or understanding is shown by the average motorist caught within an unexpected or untimely traffic jam or when a quick early morning freeze causes solid ice on every road in the area. If things go wrong, public reaction is vehement and instantly directed to the duly-elected public officials, the city government, or to supervisors and work personnel in the highway department.

Highway officials believe the general public is not adequately appraised of improved safety and reduction in highway deaths. Rather they feel the public and others unjustifiably stress corrosion damage to cars, vegetation damage, and salts in ground and surface waters, as being all too important. Infrequently, but sometimes, the well-intentioned defenders of highway salting do show a tendency to overstate their

position. We cite a few cases from the literature such as: "We might ask the question - Is a life worth a shrub", or, "I wonder how many motorists would go along with a policy that would possibly spare a tree and cost them their lives...", or, "All it (salt) does is keep some of the taxpayers around to see another winter"(2,4,5,6,7,9). At this point, let us turn to the specifics of snow removal operations and the various ways in which deicing chemicals are used.

Abrasives

Although the use of abrasives has declined, some 6-9 million tons of abrasives spread onto roads during 1966-1967 show that abrasives are still quite important for wintertime highway maintenance. Some States such as Oregon, because of alleged damage caused by deicing chemicals to automobiles and concrete roadways and structures, continue to depend almost exclusively on abrasives. Salts are used only in emergency situations(4) and data in Table I show that Oregon in 1966-1967 used only 1,000 tons of chemicals compared to 200,000 tons of abrasives.

Abrasives such as cinders and sand are treated with sodium chloride or calcium chloride at the rate of 50 to 100 lb. salt per cubic yard material. This treatment measure prevents freezing of the material in storage, and enables better handling, loading and spreading of the abrasives. Salts may be added to the abrasives in dry form or as a brine spray. This treatment also serves to increase the embedding potential of sand, cinders, etc. Abrasives are mainly used to improve traction in critical areas, especially on hills, curves, intersections, bridges, etc. It is reported where previously eight 4-ton truck loads of abrasives were required to cover 4 miles of roadway, in contrast, using salts, the same area can be covered with only one 4-ton truck load of salt. Today's safety standards are indicated as requiring immediate attention to snow and ice control before serious hazard is created. Unfortunately abrasives attack the problem after ice and snow have accumulated(4,5,9).

The Idaho Department of Highways in a recent report of April 1971(10), indicates that they will continue to rely on a "complete" sanding program, which is determined to be more feasible than complete salting. "When the public demand becomes more inclined toward the increased convenience and safety of salting than toward the monetary outlay required, then the complete salting policy or modification thereof may be more feasible." The current sanding policy of the Idaho Department of Highways gives immediate priority for sanding hazardous locations such as sharp curves, high grades, combination of grades and curves, bridge decks, interchanges and intersections. However, if availability of sand becomes critical, and/or extreme hazardous conditions develop, the Department may then consider straight salt. This report(10) attempts to economically compare the alternatives of complete salting and complete sanding vs. the present sanding policy used by the Department. In 1970, the Department expended around \$600,000 for wintertime sanding of State roads, and it is recognized

the annual cost of sanding is steadily increasing. Experiences in Oregon, Idaho and other western States show the need for realistically comparing abrasives and deicing salts with respect to cost, effectiveness, and environmental problems. The Idaho results also suggest that use of sand in place of salt particularly for less critical areas, should be given greater consideration.

Chloride Salts and Properties

Sodium chloride and calcium chloride are generally used separately, but may be mixed together to satisfy certain road conditions. Chlorides are quite prevalent in nature comprising about 0.15 percent of the earth's crust and 2 percent of seawater. Chlorides are important in the human body in maintaining critical body functions and physiological processes, and are recognized as a vital ingredient for sustaining plant and animal life. Calcium and sodium likewise are considered essential elements which respectively comprise 3.6 percent and 2.6 percent of the earth's crust. These chemicals are purchased as rock salt and calcium chloride in relatively unrefined states. Rock salt is 94 to 97 percent sodium chloride, and the ASTM specification for purchasing calcium chloride for highway use specifies a minimum of 94 percent calcium chloride(9).

Calcium chloride is appreciably more soluble than the sodium salt in water and due to its solubility, the calcium salt creates a lower freezing point and will dissolve more ice than an equal amount of sodium chloride. The calcium salt liberates heat going into solution, and has deliquescent and hygroscopic properties. The calcium salt will readily absorb moisture when the relative humidity is higher than about 30 percent, which gives it certain advantages over rock salt in highway deicing. Because it absorbs water, calcium chloride also finds use in controlling dust from unpaved roads in the summer. However, serious difficulties are oftentimes encountered in storing calcium chloride(4,5,9).

In ice control, sodium chloride is considered more effective over longer periods and cuts deeper, but the calcium salt reacts faster. Consequently, the two salts are frequently mixed in different ratios depending upon given weather conditions so as to utilize the best characteristics of both chemicals. Calcium chloride becomes increasingly effective the greater the temperature differential below freezing. Many recommendations may be found in the literature on the best ratio of calcium to sodium mix. An APWA Research Report describes a satisfactory mixture for storm conditions (other than that controlled with straight sodium chloride), as being made up of 1 part calcium chloride and 2 parts rock salt by volume. For hard-packed snow and heavy ice, they indicate sometimes a 1:1 mix is used. Mention was also made of a 15 percent calcium mix. The Massachusetts Legislative Research Council report(4) describes a 1:3 mixture of calcium:sodium as being effective near 30°F, ranging to a 1:1 mixture found effective under very severe icing conditions and very low temperatures. The Council also indicates that a mixture of two parts chemical (1:3 calcium to sodium by weight) to one

part abrasive would be almost as effective as straight chemical in melting action and furthermore would provide good skid protection(4,6).

From the standpoint of equilibrium, it has been calculated that 600 pounds of sodium chloride applied per mile of 20 foot width road coated with 0.2 inches ice (or 2 inches of snow) would melt about 10 percent of this ice cover. This is sufficient to loosen the surface bond and maintain bare pavement conditions. It should be specially noted that except under very low temperatures (below 10°F) and very light traffic, the rate of ice or snow melting will primarily depend upon traffic volume rather than the melting properties of the deicing chemicals used. Although 8,000 pounds of salt are theoretically required to completely melt a one-eighth inch covering of ice from one mile of two-lane roadway at 20°F, good highway practices would use only 300-500 pounds of salt, which when combined with traffic load, would produce adequate snow and ice removal(4). Past experience indicates that deicing chemicals are effective and economical when the snowfall is relatively light, up to depths of 2-3 inches. For heavy snowfalls there must be heavy reliance upon plowing and other mechanical means of removal(4,6).

Marine Salt

The State of Massachusetts in the early 1960's, conducted field tests comparing the efficiency of rock salt with marine (solar) salt and found encouraging results for the marine salt. This deicing agent obtained by evaporating sea water, was reported approximately equal to rock salt in cost, and was successfully used by several New England towns on their local roads(4). Marine salts are reported to have generally similar characteristics to the commercial deicers but there may be notable differences, particularly in smaller particle size of the marine salt possibly creating a faster melting action compared to straight sodium chloride. Although there is a lack of firm data in the literature, it appears that substantial quantities of salts originating from sea water, have been marketed in recent years as highway deicers. Marine salts are probably being sold separately or mixed together with commercial rock salt amounting to hundreds of thousands of tons annually.

The industry more or less uses the term marine salt as "meaning a homogeneous crystal or occluded crystal containing all of the sea's ingredients"(11). On the other hand, solar salt would seem to broadly encompass all salt derived from the ocean whether recently evaporated salt, or the salt deposits laid down many millions of years ago, today being mined from the land by conventional means. Commercially manufactured marine salt is reported to be normally produced by fractional crystallization. Sodium chloride, with a minimum of impurities, is selectively precipitated within concentrating and crystallization ponds over a rather narrow operating range of solution densities (i.e., 25.5° - 29.5° Baumé)^{1/}. The

^{1/} A term frequently used in the chemical industry to designate densities of solutions. Based upon an arbitrary scale of specific gravities developed by the French chemist Antoine Baumé. At 60/60°F, for materials heavier than water, °Bé=145-145/Sp. Gravity of material; for materials lighter than water, °Bé=140/Sp. Gravity of material-130.

large majority of calcium carbonate, calcium sulfate, magnesium sulfate and other impurities precipitate outside this range. The sodium chloride salt is separately collected, and then washed and refined to yield a reasonably high assay(11,12).

It is known that the composition of major constituents in sea water approximate 30.5% sodium, 55.1% chlorides, 3.7% magnesium, 7.7% sulfates, 1.2% calcium, 1.1% potassium, 0.2% bromides and 0.4% bicarbonates and carbonates(13,14,15). Although commercial marine salts exclude impurities to a large extent, information on product composition is not readily available. Further data on marine salt is greatly desired as to its composition; its comparative deicing efficiency; and significantly, the potential consequences of sulfates, magnesium, potassium and other available constituents possibly contributing to environmental pollution.

State Usage

The States experiencing greatest use of deicing chemicals are those located in the eastern and north-central regions of the U.S. In the 100,000-200,000 ton per year use category, we may include the States of Maine, New Hampshire, Vermont, Connecticut, and Maryland (data in Table I adjusted for sources not reporting). In the 200,000-400,000 ton category, we have the States of Massachusetts, Indiana, Illinois and Wisconsin. The leading States in highway salt consumption as of the winter of 1966-1967 were Minnesota - about 570,000 tons, Michigan - 590,000 tons, New York - 680,000 tons, Ohio - 740,000 tons, and Pennsylvania - 850,000 tons (see Table I). It is noted the State of New Hampshire although relatively small in area, has used highway salts since the mid-40's, and over this period the cumulative use of highway salts in that State alone has probably exceeded 2.3 million tons.

Highway Salt Applications

The common sequence generally starting as soon as possible after the snowfall arrives is salting the highway, plowing, then resalting as many times as necessary during the storm. In Massachusetts, salting commences when snowfall is about one-inch, and the salt is permitted to remain about 60 minutes before snowplowing. In other areas, snowplows will follow immediately behind salt application, which seems less desirable. Environmental problems are minimized by deploying chemicals as sparingly as possible to maintain safe traffic flows. However, the literature also emphasizes that the "bare pavement" policy requires frequent and liberal applications of deicing chemicals. In some cases, salts are applied as soon as or even before snow occurs, based upon weather forecast probability. We tend to believe there have been frequent instances where highway salts were used but no snow followed.

Salt application rates represent an important operational criteria. A 1966 APWA report(7) indicates that highway authorities in the U.S.

tend to fall into one of two categories using either 0.04 lb. salt/square yard/application, or 0.25 lb. salt/square yard/application. In his review of practices in Connecticut(16), Prior found that single applications of 1,000 lb. salt per mile on main highways are not uncommon; that rates of 0.14 to 0.20 lb. salt per square yard per inch of snow (equivalent to 1.4 tons per mile of two-lane road per inch of snow) are suggested for effective snow removal; and also, that annual salt used on certain highways in Connecticut may exceed 20 tons per mile. Hanes et. al.,(5) notes at 20°F to 25°F or above, recommended rates are 500-800 lb. sodium chloride per mile of two-lane road and 800-1,100 lb. per three-lane mile. However, in certain cases, rates as low as 200 lb. per mile give satisfactory results. When temperatures are below 20°F-25°F, rates are nearly the same but mixtures of calcium chloride and sodium chloride are used. Recommended ratios are in the range of 1:10 to 1:1 calcium to sodium salt.

Highway salt consumption in Maine is approximately 400 lb. per lane mile per application, equivalent to 25 tons salt per season used on a two-lane highway(17). Over the 1965-1966 winter, Massachusetts, the District of Columbia, Pennsylvania and Illinois are known to have applied an average of 20 to 37 tons of salt per lane mile. Additionally, the 1970 summary by Hanes et. al.,(5) estimates that several States apply more than 20 tons per lane mile over the season to a number of their highways. In response to this latter study(5), 13 States cited definite damage to trees and vegetation caused by highway salts, and 12 States reported incidents of water contamination. Schraufnagel from his experiences in Wisconsin, further estimates during the winter of 1964-1965, the State applied an average of 15.8 tons of salt per mile of roadway. Nevertheless, salt applications for certain counties in Wisconsin were much higher than the State average. For example, the data show that Milwaukee County over the winters of 1961-1964 applied 66.8 to 92.1 tons per year of chloride salts per mile of State highways in that county(9). We believe that certain sections of major State highways and toll roads in the U.S. currently receive in excess of 100 tons of salt per mile road during the winter season.

Although the total use of calcium chloride for dust control and road shoulder stabilization appears to be only around 20,000-30,000 tons per year in the U.S.(5), applications are relatively heavy at times and some damage has resulted from these practices. Schraufnagel(9) reports that dust control involves applications of calcium chloride around 1-2 lb. per square yard equivalent to 6 to 12 tons per mile for a 20 foot wide roadway. Road bed stabilization requires in the order of 6 to 12 tons per mile per inch of compacted depth. Therefore, a 6 inch compacted depth for a 20 foot wide road would use 36 to 72 tons calcium chloride per mile.

Costs of Highway Salts

Purchase costs for the straight chloride salts will depend upon many factors but chemical costs will fluctuate less than those required in

applying the salts onto roads and highways. Schraufnagel(18), based upon Wisconsin experiences, reports in 1967 that rock salt was about \$10 per ton delivered in bulk, and calcium chloride about \$47 per ton delivered in bag lots. He also notes that costs of both salts were lower at that time compared to 1960. A 1964 Massachusetts study(4) reports that calcium chloride was purchased in bags at \$40 per ton, and the average cost for sodium chloride (presumed to be bulk) was around \$13.50 per ton. Sodium chloride is preferably shipped in the summer months and protected in storage by use of laminated paper, canvas tarpaulins or polyethylene sheets.

A price of \$1.20 per ton was quoted for sand in Massachusetts, to which must be added hauling and spreading costs, \$6-10 per ton for spring cleanup of sand, and \$3 for each of the 25,000 catch basins in the State requiring subsequent cleaning. Current costs for sodium chloride in Massachusetts approximate \$12 per ton for purchasing rock salt, and another \$6-8 for hauling and spreading, giving a total cost around \$18-20 per ton salt applied(19). In Maine, these same functions may require higher costs ranging from \$12-15 per ton for purchasing sodium chloride and \$8-10 per ton for its application(17). Costs for mixing calcium chloride with rock salt for a 1:1 or 1:2 (calcium to sodium salt) blend are quoted around \$1.25 for each ton of calcium chloride used(6).

Since practically all deicing salt sold today is treated with anti-caking additives(20), it would seem the above costs include these anti-caking agents. Deicing salts containing added corrosion inhibitors such as the chromate or phosphate salts are reported 30-40 percent greater in cost compared to plain rock salt(21).

Operations, Equipment and Methods

The large majority of deicing salts and abrasives are currently applied to road surfaces by various mechanical means. Tail-gate spreaders and hopper-type spreaders are commonly used for highway salting. Standard dump trucks with discharge pipes; front-end loaders; angle loaders; public service trucks, jeeps, etc., equipped with ready-mounted plows; portable and non-portable melters, and other devices may comprise the snow and ice control equipment available at any one time. New York City having an extensive array of snow-fighting equipment available has recently received ninety-five "electronically-controlled" 10-wheel salt spreaders to complement its snow cleanup operations. This spreader is capable of distributing 14 cubic yards or 15 tons of salt before re-loading(22,23). Various types of snow-fighting and deicing equipment found in current use are illustrated by Figures 1 to 18.^{a/}

Chemicals are often spread in about an 8-foot concentrated width down the center of the pavement or driving lane. The disc spinner spreads

^{a/} Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the Environmental Protection Agency.

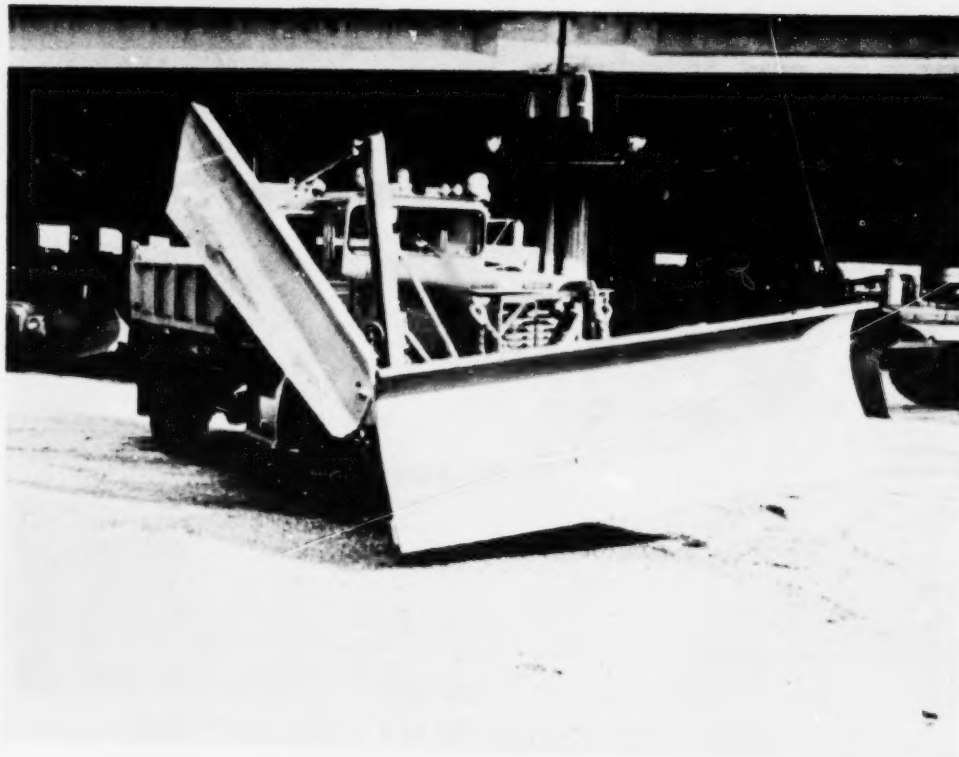


FIGURE 1
Diesel powered truck with
wing plow and straight blade



FIGURE 2
Snow blower

Courtesy of city of
Chicago, Illinois
21



FIGURE 3
Diesel powered dump truck with
salt spreader insert and snow plow



FIGURE 4
Left to right: dump truck with salt spreader
insert and plow, truck with interchangeable
plow, front-end loader, and snow blower

Courtesy of city of
Chicago, Illinois

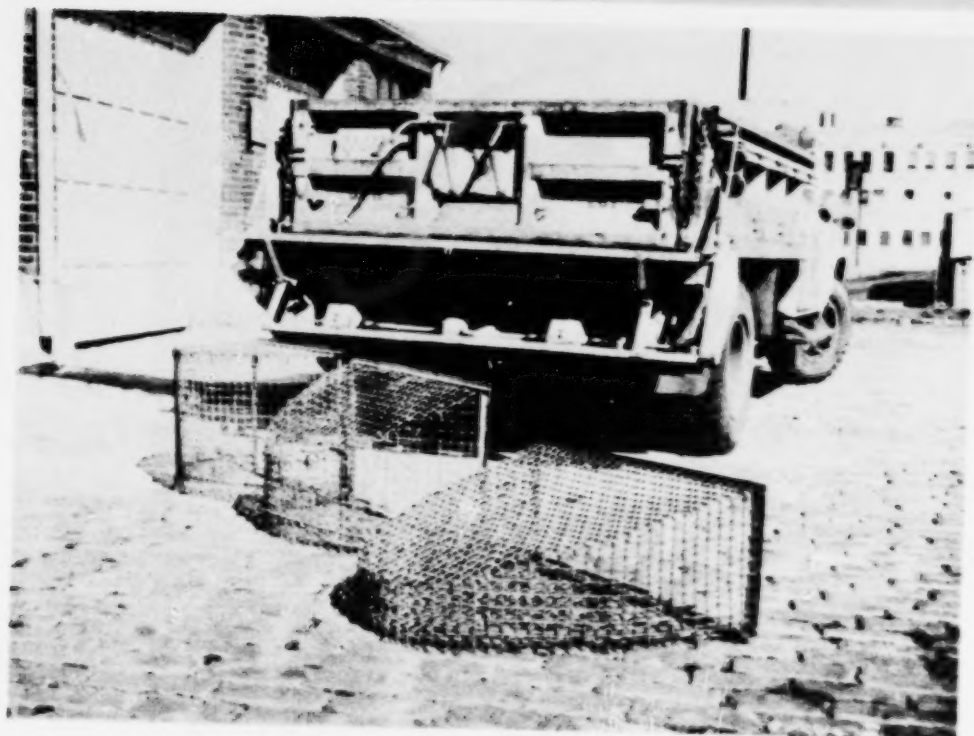


FIGURE 5
Twin-disc salt spreader with tail-gate
screens (placed inside truck body) to prevent
salt lumps from reaching feeder ports

Courtesy of city of
Milwaukee, Wisconsin

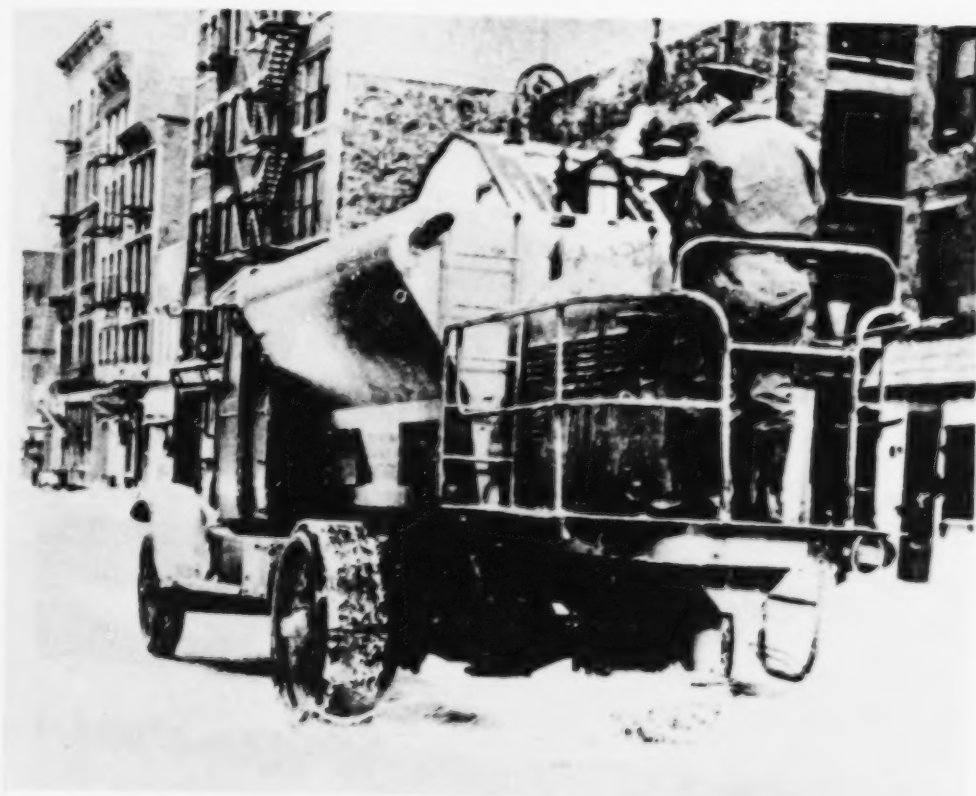


FIGURE 6
Salt spreader

Courtesy of city of
New York, N.Y.



FIGURE 7
Salt spreader

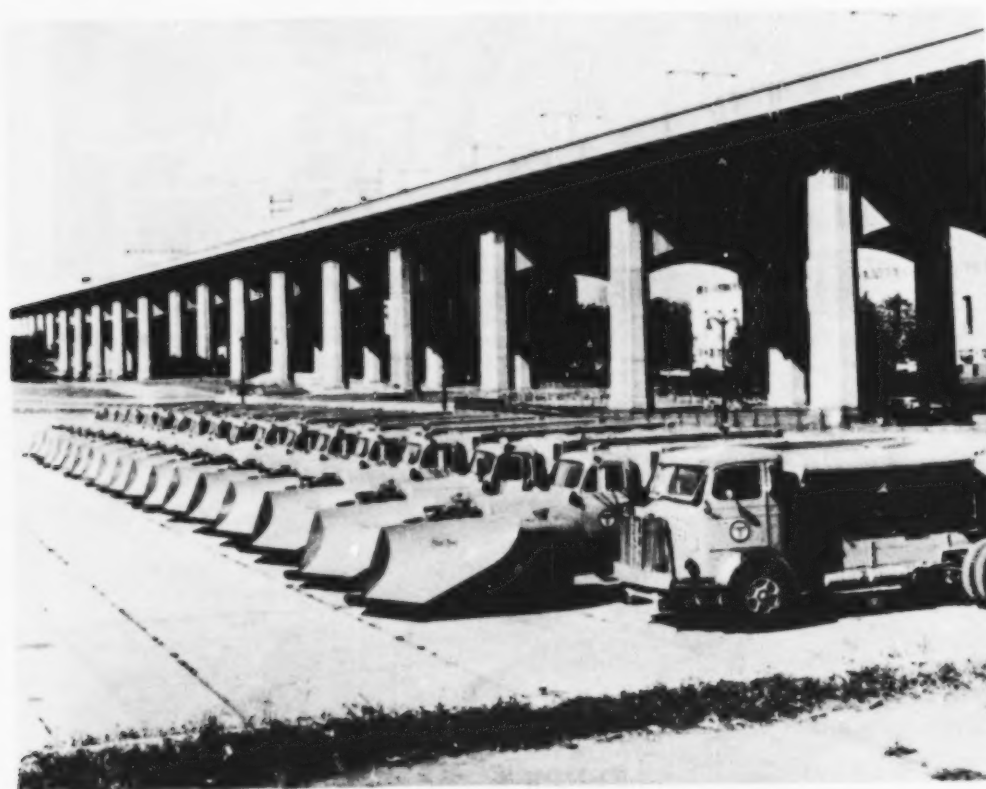


FIGURE 8
13-Ton salt spreaders with V-plows

Courtesy of city of
New York, N.Y.

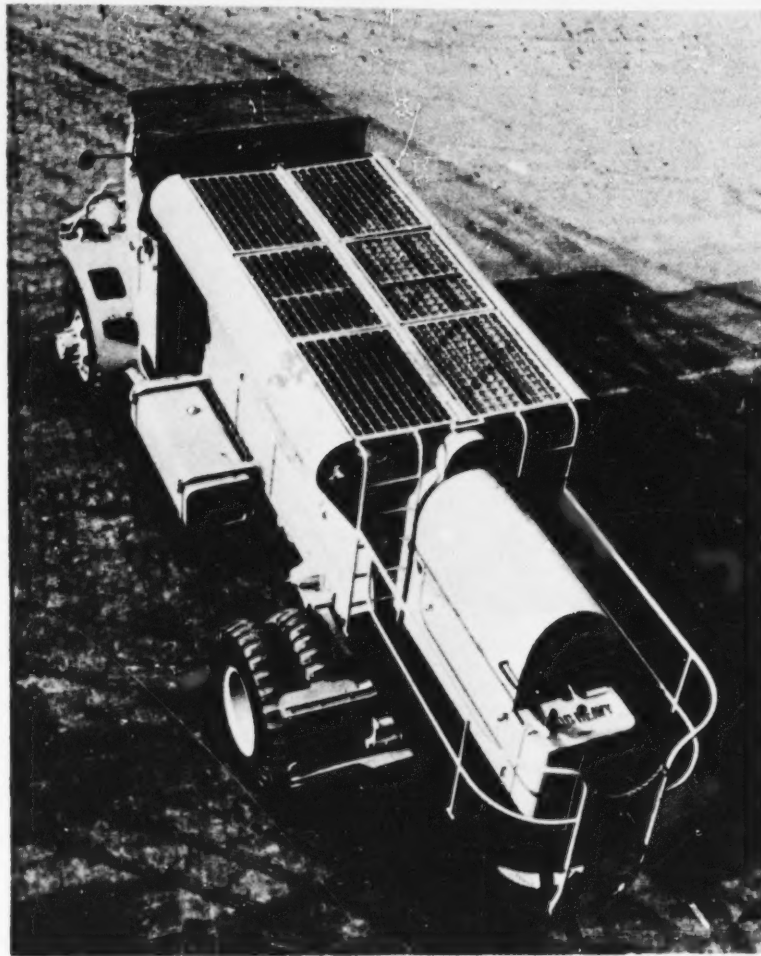


FIGURE 9
New design salt spreader with screen
grid over top to preclude salt lumps

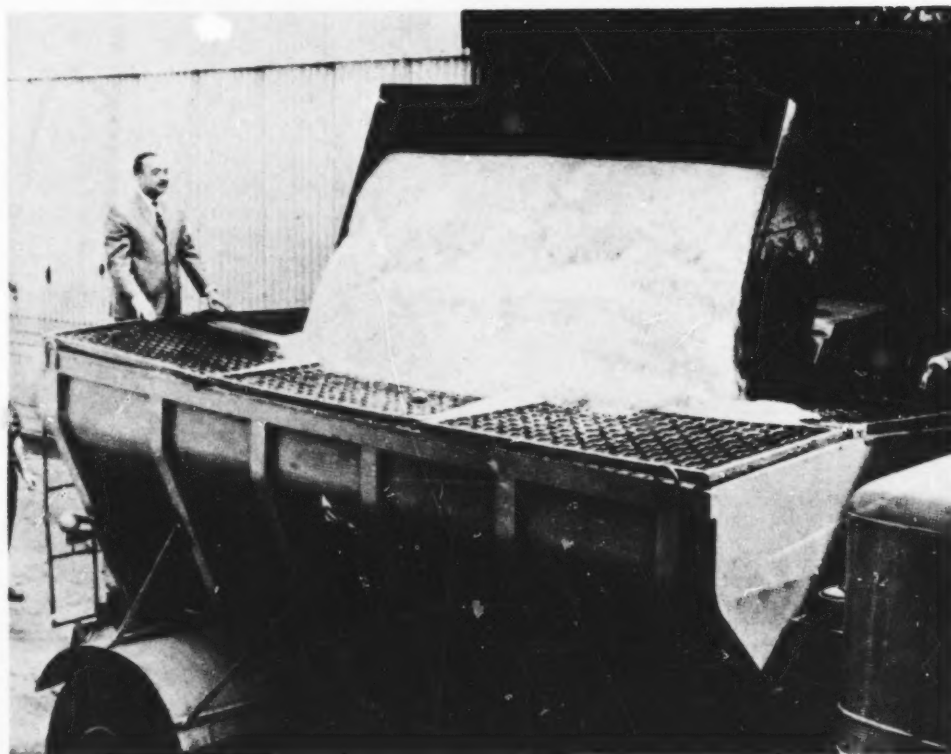


FIGURE 10
Salt spreader being loaded at salt
storage depot by front-end loader

Courtesy of city of
New York, N.Y.

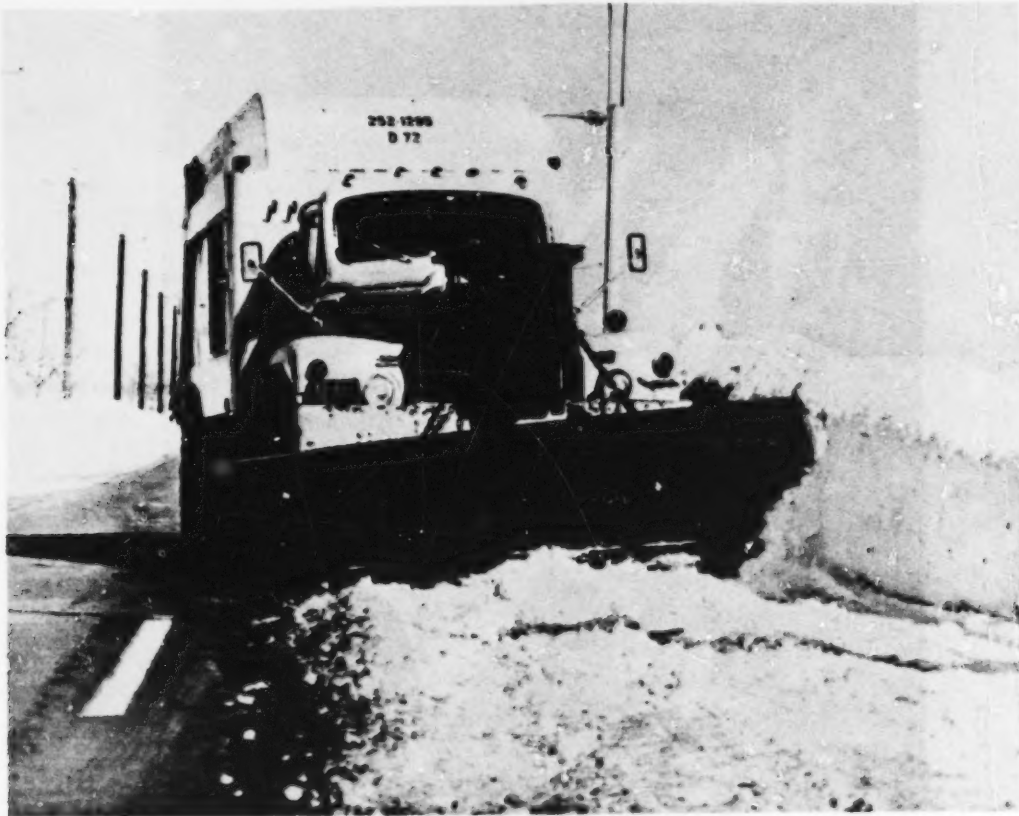


FIGURE 11
Department trucks plowing city streets



FIGURE 12
Front-end loader removing cleared
snow into receiving trucks

Courtesy of city of
New York, N.Y.



FIGURE 13
Front-end loader clearing city streets



FIGURE 14
Front-end loaders keeping city streets open

Courtesy of city of
New York, N.Y.

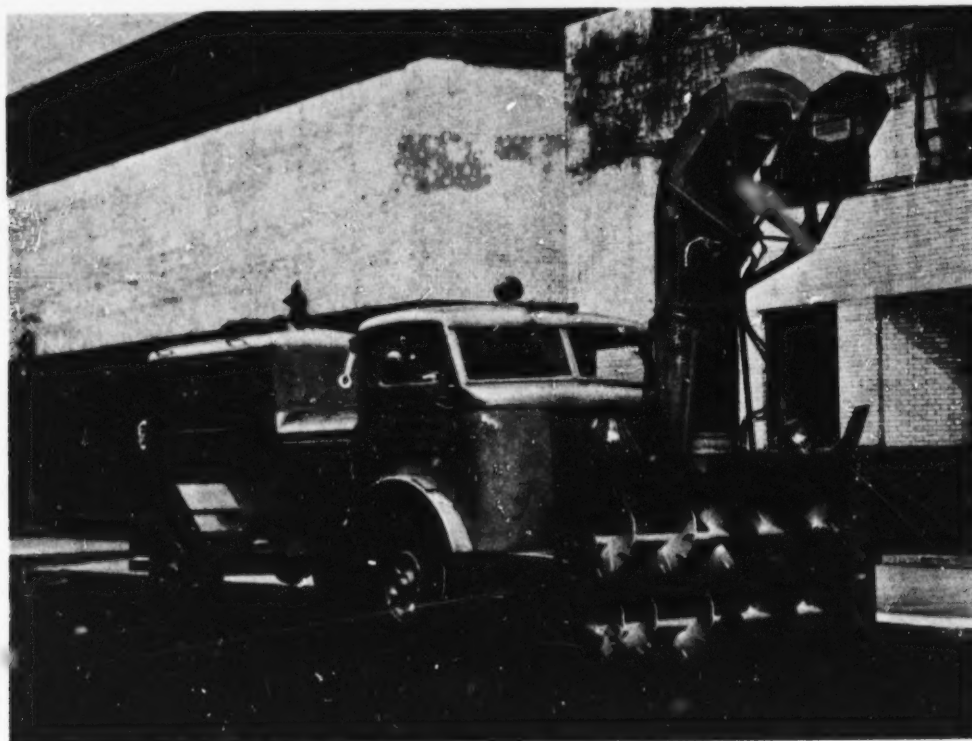


FIGURE 15
Heavy-duty snow blower

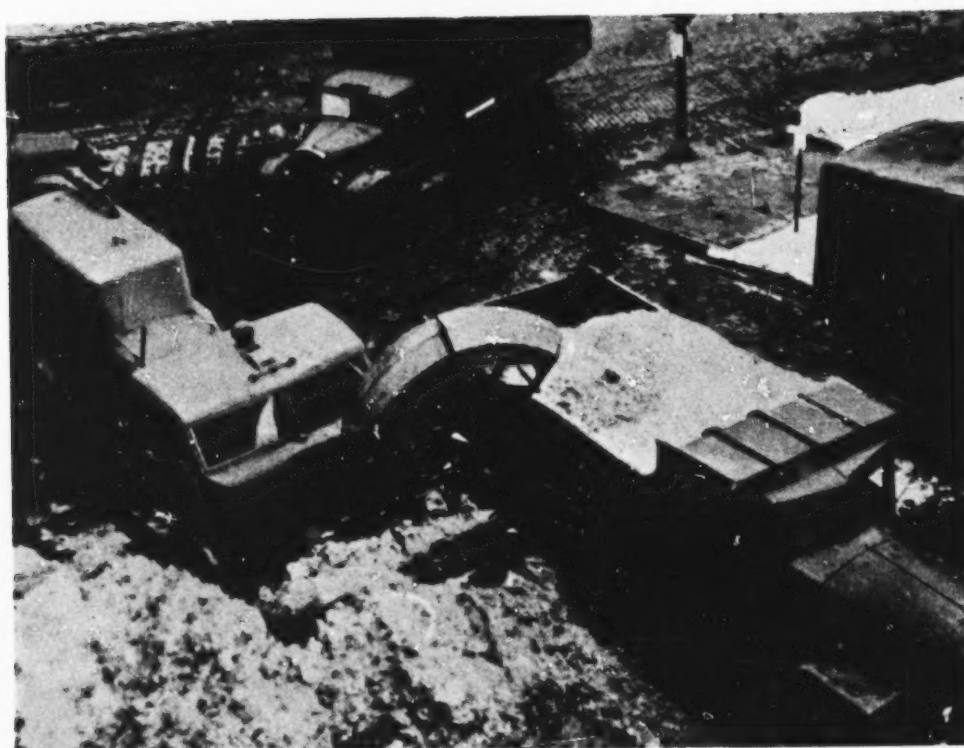


FIGURE 16
Snow blower removing street accumulated
snow into receiving trucks

Courtesy of city of
New York, N.Y.



FIGURE 17
Front-end loader depositing
snow into snow-melter



FIGURE 18
Dumping snow into nearby waterway

Courtesy of city of
New York, N.Y.

the salt over a much wider width of pavement compared to "dribbling" techniques. For many spreaders, the rate of salt application will depend upon the gate opening, spreader engine speed, and truck speed. Many spreaders appear to have an application range from 0 to about 2,000 lb. salt per mile with incremental settings of 200 lb. This equipment is frequently known to have good precision but to be lacking in reasonable accuracy. Furthermore, much of the available equipment is not metered. Volumetric devices for controlling the rate of spread include gravity and belt conveyances, or a screw drive utilized for delivery of material through an orifice. The positive displacement ability of a helical screw or grooved cylinder turning at a fixed speed is also used for metering. Within a typical town or community, the most economical approach usually involves purchase of equipment to handle the average winter storm expected and to contract for equipment and services beyond the average demand. Contract services frequently include plowing and hauling(5,6,7).

The proper application and spreading efficiency of highway salts have generated some studies but nonetheless this area has not received deserved attention. The Highway Research Board in a 1967 report(24) indicates there are several challenges presented by previous research findings. One important task is to improve present maintenance practices including the over-application of highway salts where conditions do not warrant; poor regulation of spreading equipment which distributes salt material beyond the pavement break; and too many improperly-located and inadequately-protected stockpiles of chloride salts. Greene(25) cites the viewpoint of the Bureau of Public Roads that improper calibration of salt spreaders is extremely common. Improper calibration and operation of equipment leads to excessive salt application rates, which not only increase over-all costs but also contribute to damage of vegetation and water supplies, and increased deterioration of concrete pavement and structures.

In Ontario, it is claimed \$1 million per year is saved in better application of highway salts(25), and in the State of Maine over recent years salt use is reported to have been reduced some 30,000 tons annually due to improved practices(17). Greene estimates operational savings of several million dollars per year are possible Nationwide without reducing the quality of wintertime road maintenance(25).

Partly due to improper snow control practices but also because environmental side effects are not given careful consideration, snow mixed with brine is piled alongside highways representing heavy localized salt concentrations. During salt spreading, a portion of the salt is scattered off the side of the road. In plowing, the snow may be easily pushed 15 feet or more from the edge of the pavement. This snow has been found to contain up to one-percent salt, i.e., 10,000 mg/l. After the ridges disappear, salt accumulations and burned-out vegetation are often observed as white strips parallel to the roadway. There is considerable wasting of salt due to misdirected or excessive spreading(5, 17,19,24).

Significant improvements in wintertime road maintenance practices would be derived from better field testing and control, good equipment with good maintenance schedules, greater use of mechanized equipment, frequent calibration, increased reliance and improvement of salt metering instrumentation, education and awareness through the ranks particularly at the working level, concerted effort and increased training most appropriately carried forth at the State highway department level, and due consideration given to proper environmental protection.

Besides chemical melting, various methods of thermal melting are available which may become more prominent in the future. External and in-slab thermal melting systems have greatest application in areas where any accumulation of ice and snow is considered extremely hazardous. Such areas include expressway ramps, bridge decks, busy intersections, toll plazas, etc. External systems are either gas or electric operated and utilize infrared energy for melting. In-slab systems may comprise embedded, electrically-heated cable, pipes carrying heated liquid or steam, or electrically-heated reinforced wire mesh. In-slab systems, although protected, are subjected to stress and strain caused by slab movement and invite high maintenance and repair costs because the system is buried within the slab. External systems are easier to maintain but are more vulnerable to damage caused by vehicles, vandalism, and similar conditions(6,7). Electric grids were installed in a test section of a street in Washington, D.C., but the system was reported too high in cost and power demand to enable widespread use(26).

In contrast to thermal melting systems which prevent the formation of ice and snow, "snow melters" are available used in clearing streets as an alternative to the ever-rising costs of snow hauling and dumping. These machines which come in various sizes up to 85 tons per hour generally consist of a heat source, melting chamber, and discharge system. Mobile melters are deployed on urban streets with discharge into storm drains, whereas stationary or pit melters are centrally located or situated in heavy-use areas such as airports, large parking lots, etc.(6). An 80 ton/hour malter can handle 6 inches of snow on 200,000 square feet of pavement in about 3.5 hours. Description was given(7) of a 75 ton/hour melter in Boston positioned at a street intersection and fed by two 3-cubic yard front end loaders. Lockwood et. al.(7) comment that unless streets are so narrow as to impede movement of trucks, there is little savings in removal time provided sufficient trucks are on hand to otherwise equal the capacity of the snow melter.

Purchase of a snow melter is generally based upon savings in cost of hauling and dumping snow. As of 1965, there were some 50 mobile and stationary snow melters available in the U.S. and Canada(6). Special conditions may justify the use of snow melters or installation of thermal melting systems described above. However, even today both methods are generally considered quite expensive compared to spreading of deicing salts on city streets followed by normal snow removal operations.

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Other Deicers

There is consistent opinion in the literature that possible alternatives to sodium chloride and calcium chloride, which are reliable and economical, will not come into large-scale use in the foreseeable future. Substitute deicing compounds which meet special conditions or which are otherwise suggested for possible use include urea, urea combined with calcium formate, the various chlorides such as magnesium, potassium, aluminum and lithium chloride, ammonium acetate, methyl and ethyl alcohol, isopropyl alcohol, ethylene glycol, glycerol, aldol, mixed amides, and chemical dyes. From available data, it appears that the above chemicals are considerably higher in unit cost compared to rock salt. Experience, operational data, and knowledge of environmental effects are lacking for the substitute deicers. However, certain of these compounds are suspect in terms of toxicity, increased corrosion of metals and concrete, eutrophication potential, and hazards in handling(4,5,6,7,18).

Urea, mixtures of urea and ammonium-sodium nitrate and phosphate salts, and mixed amides appear to be most frequently deployed for airport runway deicing. Urea is less corrosive than sodium chloride but must be used in quantities about twice that for rock salt, and is about 6 times higher in unit product cost. The aviation industry is mainly concerned about stress corrosion in aircraft metals, consequences to the air frame and structural failure. Cost of chemicals and effects upon concrete pavement and ground structures are of secondary importance. Ethylene glycol has in the past been used by airports and is also important for deicing car windshields. Calcium chloride and the ammonium-potassium nitrate and phosphate salts are sold for home use in clearing sidewalks and driveways of ice and snow(4,5,6,8,18).

Salt Storage

Cities, towns, counties and other highway authorities receive large quantities of deicing salts shipped by truck, barge and rail car. These shipments generally arrive throughout the summer and fall months. The governmental authority should logically plan and select appropriate sites for storing these materials for wintertime use. Salt suppliers recommend that these products be received and stockpiled over the summer, usually no later than September. As more cities, counties, and States are changing to "straight salt" programs, timely deliveries are becoming more difficult. For deliveries late in the year, many towns and cities may pay more for shipments that require greater time to receive. Replacements in January, February and March may be extremely scarce or almost impossible to locate, particularly during severe winters when many authorities are seeking additional stock(20,27). Typical salt storage areas in New York City, Chicago and Milwaukee are shown in Figures 19 to 23. Figure 24 illustrates a covered salt stockpile in Toledo, Ohio. From the standpoint of water pollution control, fully covered stockpiles as illustrated in Figures 23 and 24 are highly preferred over open storage.

Bulk salt represents the most economical material obtainable and bulk salt storage generally provides maximum availability and convenience at least overall cost. The large majority of highway salts have been previously stored outdoors with or without covering, and placed directly on the ground or upon bituminous or concrete pads. In recent years however, more highway authorities have turned to protected or roofed enclosures and others have provided suitable covering for open stockpiles. Enclosed structures are recommended in order to: 1) abate contamination of nearby streams, wells, and groundwater by excess salt runoff; 2) improve aesthetics in the local area; 3) prevent formation of lumps and reduce frozen crust in the salt piles; 4) eliminate heavy, caked salt in the pile thereby facilitating easier handling by mechanical equipment; and 5) enable better control over stored materials and more efficient loading and unloading(20,27).

Deicing salts may be stored in unused buildings, garages, covered sheds, elevated storage bins, domed structures, cribs, and upon elevated platforms, or pallets. Stockpiles outdoors are preferably placed on storage pads and should definitely be covered with heavy tarpaulin, canvas or other protective materials. Salt storage sites should permit easy access by trucks, front-end loaders and similar equipment, and be situated so that trucks and salt spreaders do not have to "dead-head" long distances before reloading. The Salt Institute recommends that all storage pads, cribs and similar structures be located at sites completely free of groundwater. They suggest that bituminous pads be placed upon crushed aggregate and salt-stabilized subgrades. Pads should be crowned to enable drainage away from the pile on all four sides. Additionally, drainage ditches, pipes or tiles may be necessary around salt storage areas to prevent contamination of local ground and surface water supplies. In certain instances, impoundment basins may be essential to capture and retain this salt drainage(20,27).

Examples of the types of salt storage facilities most frequently used in the United States are illustrated in Figures 25 to 37. It is noted that construction costs as given for these storage facilities were prepared around 1965, and are undoubtedly somewhat below current estimates. The more expensive structures are often reported to be the least expensive to use depending on local climate, amounts of stored materials, type of equipment available and services. For bulk salt storage, the following figures are useful:

Stored salt = 80 lb. per cubic foot
One cubic yard salt = 2,160 lb.
One ton salt = 25 cubic foot
One ton salt = 0.926 cubic yards

With the natural angle of repose of rock salt of 32° , 1,000 tons of salt stored in a conical pile covers a ground area circumscribing a circle 67.1 feet in diameter or 3,540 square feet. The height of the pile is 21 feet and the exposed surface area of the pile (for purposes of covering) is about 4,180 square feet(27).

In a Salt Institute publication of 1967(20), it is reported the State of Ohio has used various wooden structures providing shelter for up to 100,000 tons bulk salt. Floors are constructed of asphaltic concrete and the capacities of individual structures range from 200 to 1,000 tons salt. The State of Iowa indicates they have built some 160 pole-wood structures giving protection to stored salt. Three sizes are used: a 20x30 foot building with 100 tons capacity; a shelter 20 by 40 feet with 150 tons capacity; and a structure 28 by 56 feet holding 300 tons of salt. The buildings are supported with treated timbers 6x8 inches lined on the inside with 2x12 inch lumber, and have galvanized steel roofs and sliding doors.

Fitzpatrick(28) of the Ontario Department of Highways has described a dome-like structure or "beehive" now being used to store large quantities of sand-salt mixtures in the Province. The beehive is rather unique in storing up to 5,000 cubic yards of sand-salt under one roof with a clear span free of posts, poles or pillars. Trucks, front-end loaders and other equipment can easily move about the structure for loading and unloading. The beehive during and after assembly is shown in Figures 38 to 43. A 24-inch thick concrete foundation is used into which is inserted a series of posts inside the vertical walls for purposes of adding a sand retaining ring so as to keep the stored material away from the base of the structure. The beehive approximates a cone 100 feet in diameter by 50 feet high, and consists of a 20-sided shell constructed of 2x6 inch lumber overlaid by three-eighth inch plywood and asphalt shingles. Each of the 20 sides is in the form of an isosceles triangle made up of 9 panels diminishing in width to the top of the structure. The 20 sides are bolted together and the top is added to complete the beehive. The Department of Highways indicates they can load the building with sand up to 80 percent of full capacity, and with improved handling procedures they will eventually fill the entire dome. The structure requires about 900 man-hours for completion once the pad has been laid. Costs are reported around \$3.50 per square foot of floor area equal to \$5.00-\$6.50 per ton of sand-salt mixture stored(28).



FIGURE 19
Open salt storage pile, downtown Chicago, Ill.

Courtesy of city of
Chicago, Illinois



FIGURE 20
Open salt storage pile, Milwaukee, Wis.
estimated quantity 41,000 tons

Courtesy of city of
Milwaukee, Wisconsin



FIGURE 21
City stockpile of rock salt remaining after
winter's use, mid-February, Milwaukee, Wis.

Courtesy of city of
Milwaukee, Wisconsin



FIGURE 22
Typical salt storage pile in
downtown New York City

Courtesy of city of
New York, N.Y.



FIGURE 23
Moving salt by front-end loader
inside enclosed storage structure

Courtesy of city of
New York, N.Y.

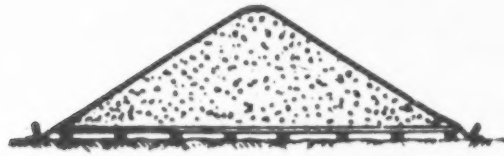


FIGURE 24
Covered salt stockpile located adjacent
to the Maumee River in Toledo, Ohio

Courtesy of the
Salt Institute,
Alexandria, Va.

FIGURE 25

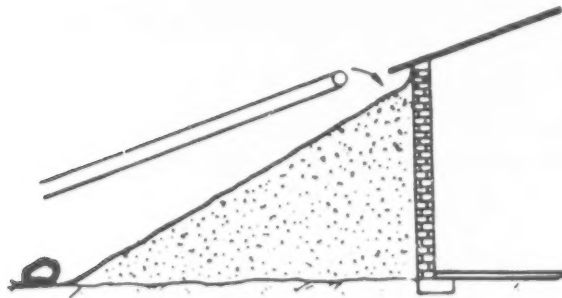
Approx. Construction Cost \$3 to \$5 per ton of capacity



Rock salt can easily be stored outdoors. This shows a rectangular-conical pile of bulk salt covered by a tarpaulin held down by stakes. The platform is approximately 30' square and is composed of 3" planks held up by 4" by 4" wood sills. It will hold approximately a 40-ton minimum carload of bulk salt.

FIGURE 26

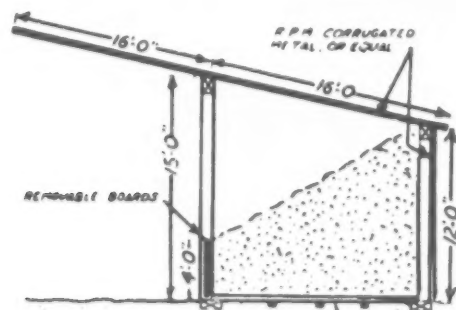
Approx. Construction Cost \$3 to \$5 per ton of capacity



Rock salt may also be stacked against a garage or shed wall. Here a portable conveyor stacks it. The pile is covered by a tarpaulin and anchored at the lower end by large rocks.

FIGURE 27

Approx. Construction Cost \$3 to \$5 per ton of capacity

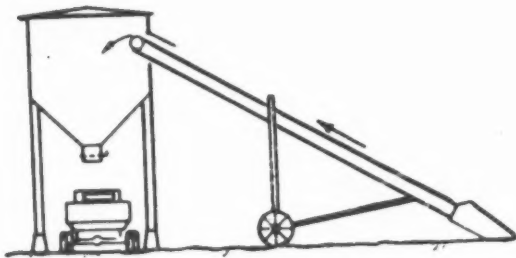


Open bin storage like this is favored by many Ohio communities, and the dimensions shown here are given to scale. The roof has a very large overhang in order to protect the open salt from the weather. Trucks are backed up to the bins and the salt is partly dumped and partly shoveled in. It is removed by shoveling into trucks, or portable conveyors may be used.

Courtesy of the
Salt Institute,
Alexandria, Va.

FIGURE 28

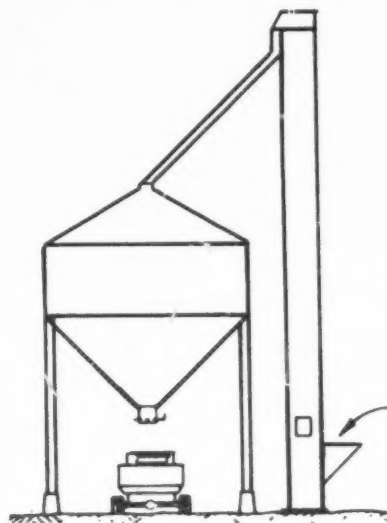
Approx. Construction Cost
\$50 to \$75 per ton of capacity



Standard steel bins like those used by contractors for cement, sand and gravel provide excellent rock salt storage space. Dump trucks feed salt into the portable conveyor, which carries it up to the bin.

FIGURE 29

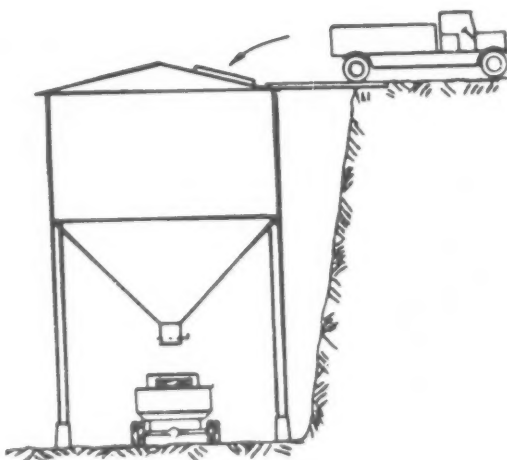
Approx. Construction Cost
\$50 to \$75 per ton of capacity



The same type of bin as that shown in Figure 28, except that a vertical chain and bucket elevator is used.

FIGURE 30

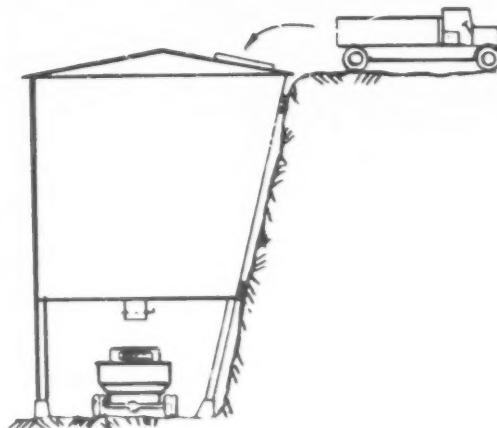
Approx. Construction Cost
\$50 to \$75 per ton of capacity



In hilly communities the bin may be placed close to a hillside to facilitate loading.

FIGURE 31

Approx. Construction Cost
\$50 to \$75 per ton of capacity

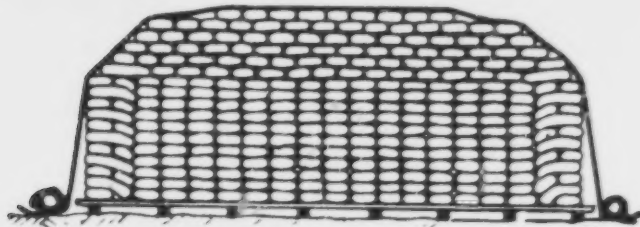


This variation on the bin in Figure 30 follows the contour of the hill.

Courtesy of the
Salt Institute,
Alexandria, Va.

FIGURE 32

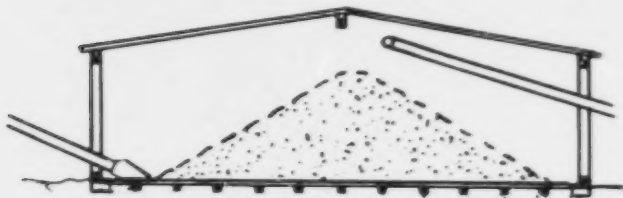
Approx. Construction Cost \$15 to \$20 per ton of capacity



Many communities use this method of storing bags of rock salt outdoors. The sketch shows 50 tons of bags placed on a platform about 30' wide with the bags many layers deep. The planks are 3" and supported by 4" by 4" sills. The bags are covered by a tarpaulin held down by rocks. Note the method of piling bags on the outside of the pile. Trucks are apt to bump into the pile while backing up for loading, and it is important that the stacking be in such a way that the bags stay firmly in place or else fall inward.

FIGURE 33

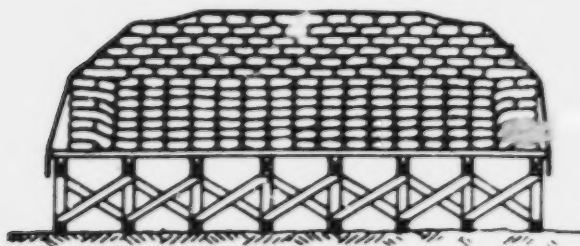
Approx. Construction Cost \$10 to \$30 per ton of capacity



Bulk salt stored under a shed. The salt is loaded in by a portable conveyor, which is also used for getting it out and onto trucks for distribution.

FIGURE 34

Approx. Construction Cost \$20 to \$30 per ton of capacity



This piling arrangement, similar to that in Figure 32, features a platform about 3' off the ground in order to facilitate loading onto trucks. Under these conditions, the storage is not over 40 tons of salt as a rule. The tarpaulin is held in place by tying underneath to the posts.

Courtesy of the
Salt Institute,
Alexandria, Va.

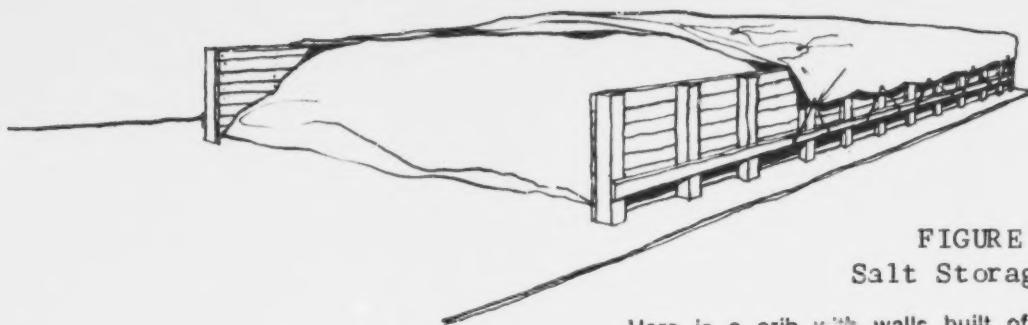


FIGURE 35
Salt Storage Crib

Here is a crib with walls built of 2x6 tongue and grooved creosote treated material. Posts are railroad ties set three feet apart on center. Note the 2 x 4 cleat nailed to crib wall posts as tie-down for tarpaulin or other covering.

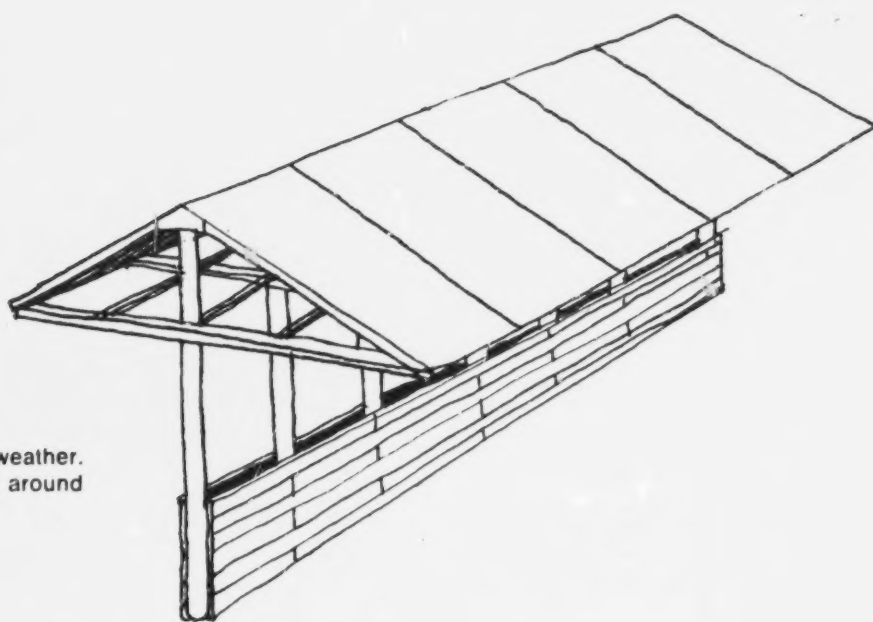
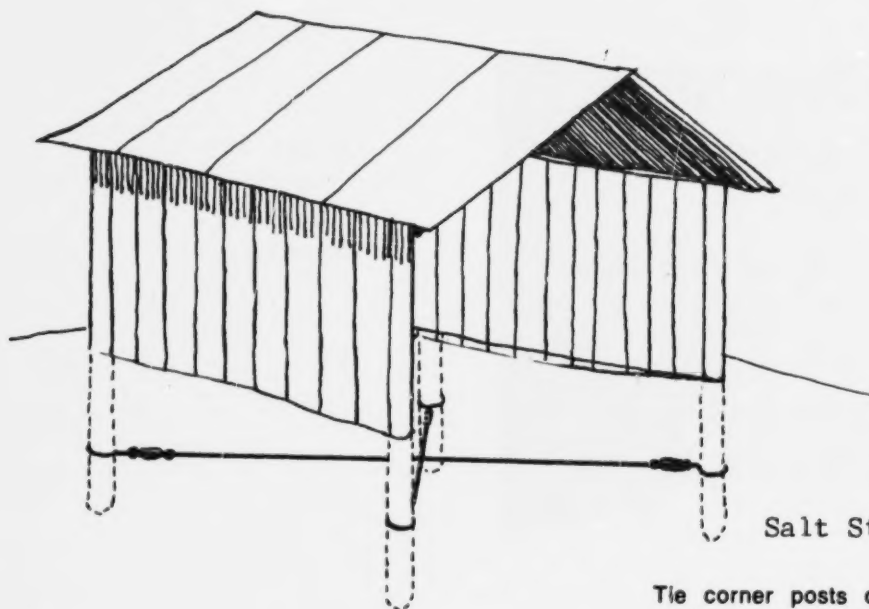


FIGURE 36
Salt Storage Shelter

Umbrella structure protects material from weather. Panel on both sides keeps salt from collecting around posts.



Courtesy of the
Salt Institute,
Alexandria, Va.

FIGURE 37
Salt Storage Building

Tie corner posts of storage buildings together with underground galvanized cables with turnbuckles.

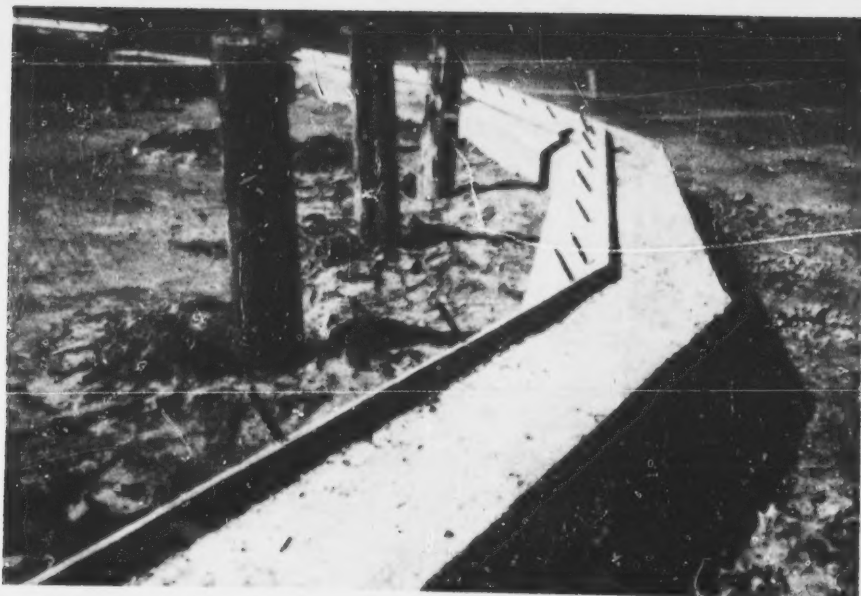


FIGURE 38
The "Beehive" -
Concrete base forms
removed; note posts
for retaining ring
roughly placed

FIGURE 39
The "Beehive" -
Third ring of panels
being placed; placing
of panels by
electrical truck

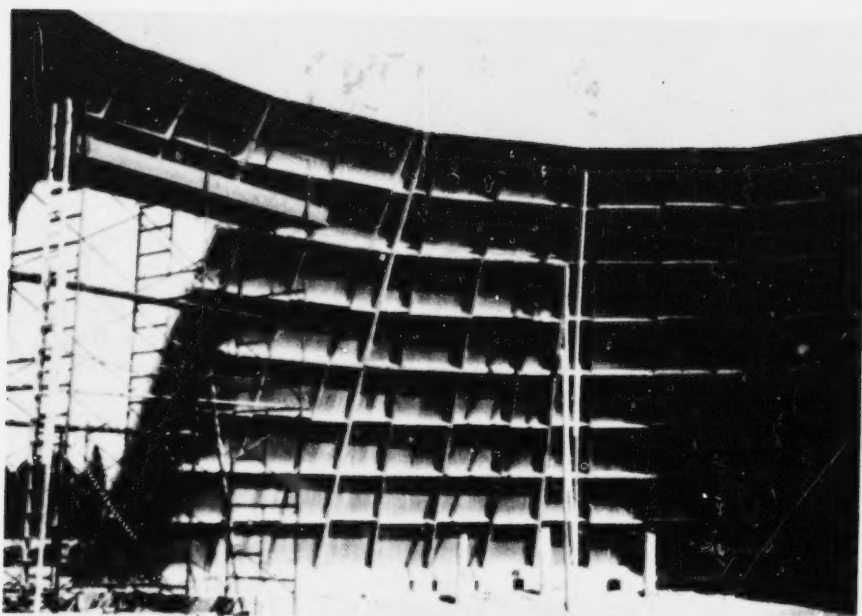


FIGURE 40
The "Beehive" -
Fourth ring
completed

Courtesy of J. R. Fitzpatrick,
Dept. of Highways, Ontario, Canada



FIGURE 41
The "Beehive" -
Building with all
panels in place; note
air vents at top

FIGURE 42
The "Beehive" -
Method of loading;
first stage by
truck and dozer

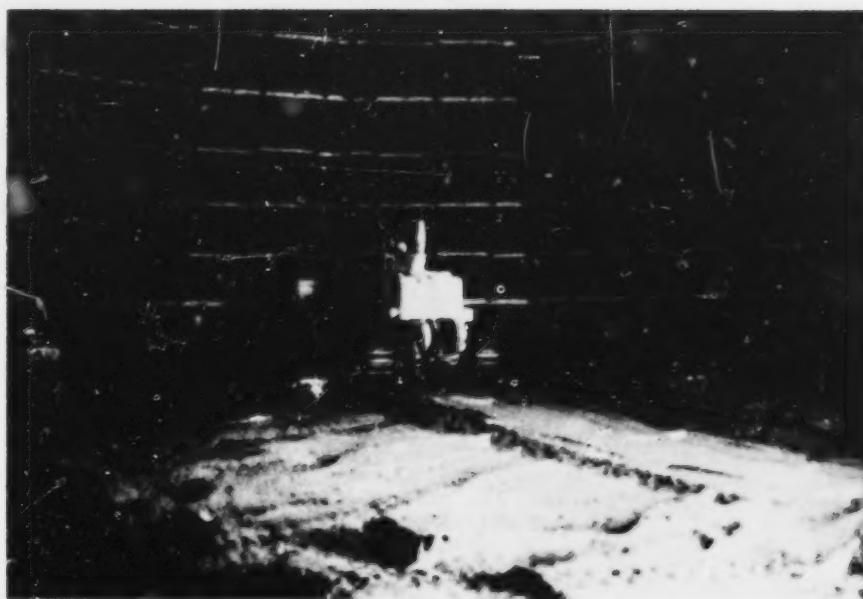


FIGURE 43
The "Beehive" -
Method of loading;
second stage by
conveyor

Courtesy of J. R. Fitzpatrick,
Dept. of Highways, Ontario, Canada

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SECTION IV

RAINFALL AND OTHER SOURCES

The amount of impurities and the mineral quality of rainwater, particularly chloride content, has been of continued interest to scientists, agronomists, chemists, and others. Special stormwater studies conducted by the Taft Sanitary Engineering Center in Cincinnati, Ohio provided analysis of rain samples of August 1963 through November 1964(29). Average data for rainfall at this location shows the following: pH - 4.8; total suspended solids - 13.0 mg/l; chemical oxygen demand - 16.0 mg/l; total nitrogen (N) - 1.3 mg/l; inorganic nitrogen (N) - 0.7 mg/l; hydrolyzable phosphates (PO₄) - 0.24 mg/l; and organic chlorine (mostly reflecting chlorinated hydrocarbons) - 0.28 mg/l.

Junge et. al.,(30) studied rainfalls in many areas of the United States and concluded that the oceans are a major source of chlorides in rainwater. They found that calcium content of rainfall is the highest for storms over the Southwest principally derived from dust storms(29,30). Fanning and Lyles(5,31) believe that salt content of rainwater decreases in proportion to the logarithmic distance inland. The rainfall at Cirencester, England, was found to contain an average chloride content of 3.2 mg/l over a 26-year period equivalent to an annual deposit of 36 pounds NaCl per acre(32). At Mount Vernon, Iowa, the average level of chloride in rainwater was 10.6 mg/l from October 1913 to June 1914, and 7.1 mg/l from October 1914 to June 1915(5,33,34). The following table prepared by Klein(35) compares rainwater with surface waters, groundwaters, sewage, and seawater in terms of average chloride content.

TABLE II
CHLORIDE CONTENT OF VARIOUS WATERS^{a/}

<u>Type of Water</u>	<u>Chlorides (mg/l)</u>
Rainwater	2
Upland Surface Water	12
Unpolluted River Water	<15
Spring Water	25
Deep Well Water	50
Drinking Water	10-20 (but variable)
Weak Sewage	70
Medium Sewage	100
Strong Sewage	Up to 500
Urine	4,500-5,000
Sea Water	20,000

^{a/} From Klein, 1959(35)

Besides chlorides being universally present in rainfall, other sources of chlorides include the leaching of salt from underlying rocks and soils which is more common in the western and mid-west U.S.; salt contribution by domestic, commercial and industrial wastewaters; salinity present in irrigation return flows particularly in the western States; air pollution fallout from industrial stacks, automotive emissions, open dumps, etc. It is much beyond the scope of this report to describe and document each and every source of chlorides. The information given herein focuses on road deicing salts, although some data are given for rainfall and municipal sewage. Unless indicated otherwise, extreme care has been taken with all data presented in this report to describe the various effects and consequences of highway salts on the environment, and to exclude all other influences.

SECTION V

SEWAGE

Domestic and municipal sewages contain high chloride content relative to surface and groundwaters, but quite low compared to sea water (see Table II). Chlorides are generally considered a persistent or non-degradable type of pollutant. The chloride content of sewage is essentially unchanged as it passes through conventional sewage treatment plant processes. Furthermore, the chlorides in treated waste effluents are not significantly changed after discharge into receiving surface water, nor are the chlorides biologically assimilated to any large degree. These chloride sources directly add to the total chlorides already existing in surface streams(5, 9,35).

Human wastes, particularly urine, contain appreciable amounts of chlorides. Sawyer indicates the excreta represents an average of about 6 grams chlorides per person daily, and adds approximately 15 mg/l chlorides to the composite sewage flow(9,36). Domestic sewage has a chloride level around 50 mg/l(9,37). O'Conner and Mueller(38) cite values of 5-9 grams chlorides per person daily, equivalent to 4-7 pounds per capita per year. To allow for kitchen wastes and the effluents from commercial and small manufacturing establishments, a value of 20 pounds chlorides per capita per year is often used. This is equivalent to 40-80 mg/l chlorides added to sewage, depending upon the per capita water consumption. In Madison, Wisconsin where the water supply has a hardness of about 300 mg/l, Schraufnagel(9) indicates household water softening could easily raise the chloride content in domestic sewage by 100 mg/l.

The chloride level in the effluent from the Nine-Springs sewage treatment plant in Madison, Wisconsin was 287 mg/l in April 1965(9). At Green Bay, Wisconsin, operational data collected by the Metropolitan Sewerage District showed average chlorides of 255 mg/l in the treatment plant sewage over the 12 months of 1964. In contrast, the municipal water supply of Green Bay has a chloride content of only 7 mg/l. It is noted that monthly chloride values in Green Bay sewage were 285-312 mg/l from January through April representing the period of street deicing, compared to 196-283 mg/l over the remaining months of 1964(9).

An excellent record has been maintained on chloride content of incoming sewage and effluents taken every 8-hours at the Jones Island East and West treatment plants of the Milwaukee Sewerage Commission over the period of at least the last five years. The question has been raised whether increasing chlorides, particularly in the wintertime, have any possible effect on Milwaukee treatment plant efficiencies. This question cannot be adequately answered. Nevertheless the summary of monthly chloride values from 1965-1969 given in Table III shows a well-defined annual pattern. There was little difference in chloride content between treatment plant influent and effluent(39).

It is readily observed that chloride content in Milwaukee sewage was highest in the winter months of January, February and March coinciding with the period of street salting and snowmelt. The next highest chloride values were recorded for the months of December and April. Milwaukee has an extensive combined sewer system serving approximately 15,000 acres, of which about one-half is in the downtown area. Street runoff and snow melt are collected into these combined sewers and received at the Jones Island treatment plants. Higher concentrations of chlorides in municipal sewage during the winter is believed to be a typical pattern in many cities due to highway salting and the lower sewage flows experienced at this time of the year.

TABLE III
MONTHLY CHLORIDES AT MILWAUKEE SEWAGE TREATMENT PLANT
(mg/l), 1965-1969^{a/}

<u>Month</u>	<u>Average 1965-1969</u>	<u>Range</u>
January	203	175-245
February	200	190-230 ^{b/}
March	196	170-230
April	172	160-185
May	154	140-160
June	137	120-155
July	126	105-145
August	125	110-135
September	127	115-140
October	131	120-150
November	140	125-160
December	169	150-190

^{a/} From Milwaukee, Wisconsin Sewerage Commission, May 1970(39).
^{b/} Excludes one February value.

Milwaukee personnel indicated to the best of their knowledge, there are no unusual or extraneous contributions to the sewerage system in the wintertime that would not also exist in the summertime(39). Thereupon, total daily chloride loads were calculated for both winter and summer months. Each monthly chloride value was an average of approximately 240 separate samples. It is shown that average daily chloride loads in the wintertime are 140-170 tons, compared to 90-110 tons per day in the summertime. For separate years of record, chloride loads were 40-50 percent higher in winter compared to summer.

The Milwaukee data also show surprisingly high chloride sewage concentrations for individual days, e.g., 570-600 mg/l for January 16-18, 1969,

and 500 mg/l for February 26, 1969. These chloride loads were around 330 tons per day or three-fold the normal summertime loads. Additional results collected by the Milwaukee Sewerage Commission on January 16, 1969 for chloride levels in the Milwaukee River and other major waterways in the Metropolitan area are given in Table IV. The large majority of chlorides found in the Kinnickinnic, Menomonee and Milwaukee Rivers on January 16 is believed directly attributable to deicing salts placed on the streets and highways in the Milwaukee area. The Commission reports(39) that over the last two years, annual salt application by the city of Milwaukee has been around 36,000 tons, and another 90,000 tons of salt have been applied by Milwaukee County. Direct street runoff from salted streets in Milwaukee during mid-January 1969 likely contained chlorides in the range of 2,000 to 5,000 mg/l.

TABLE IV
SPECIAL RIVER SAMPLING, MILWAUKEE SEWERAGE COMMISSION,
January 16, 1969^{a/}

<u>Location</u>	<u>Water Temperature (°C)</u>	<u>Chlorides (mg/l)</u>
Kinnickinnic River at Chase Avenue	10.0	2,005
Menomonee River at 13th St. and Muskego	10.5	200
Menomonee River at 70th and Honey Creek Pkwy.	5.0	2,730
Milwaukee River at Silver Spring Road	4.0	2,680
Milwaukee River at Port Washington Road	6.5	1,510

^{a/} Records received from the Milwaukee Sewerage Commission, May 1970(39).

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SECTION VI

RUNOFF FROM STREETS AND HIGHWAYS

Wisconsin Studies

Schraufnagel reports(9) during 1956-1957 that sampling stations were established throughout Wisconsin to study the runoff from salt-treated highways. In the Chippewa Falls area, wintertime highway runoff was found to contain up to 10,250 mg/l chlorides, but the receiving stream did not exceed 46 mg/l chlorides. Street runoff during the summer contained only 0-16 mg/l chlorides and the receiving stream had 0.5-2.0 mg/l chlorides. In Madison, Wisconsin, wintertime street runoff had chloride levels ranging up to 3,275 mg/l. It is interesting to note for street runoff in Madison, suspended solids were as high as 3,850 mg/l, reflecting considerable sand and dirt flushed off the streets during the winter. This drainage generally had BOD levels in the range of 20-30 mg/l, although 3 of the 12 samples contained around 100 mg/l BOD. For another case in Wisconsin of drainage originating from a large snow pile along Lake Monona, this runoff showed a chloride level of 1,130 mg/l(9).

Syracuse, New York

The fate of deicing salts following their application onto streets and highways is not precisely defined. It is known that these salts within the hydrologic system may be stored in the soils, groundwater, and vegetation comprising the roadside environment. Hawkins(40) believes that deicing chemicals may also be stored in the street itself, including: the snow and ice cover; on the street surface; and directly within the street masonry concrete, cobbles and other street construction materials. Hawkins observed summer "leakage" of salt upward onto the surface of street concrete and cobbles for several hills and grades in Syracuse, New York, previously receiving heavy amounts of deicers. A white-colored cast on the road surfaces and interstices persisted well into the early fall, and the presence of salt was easily confirmed by the "fingertip"-taste test. The resupply of salt from lower depths in the street layer or below the street was strongly suggested by the reappearance of salts after spring and summer rains. These salts find their way into street and storm sewers throughout most of the year(40).

Chicago, Illinois

During the winter of 1966-1967, the American Public Works Association studied the chloride content in runoff from Kennedy Expressway in downtown Chicago, Illinois. The highway drainage area consisted of 102 acres of which about half, or 52 acres were paved. Runoff samples were collected from February 16 to April 1, 1967, during which time

there was 14 inches of snowfall and 126 tons of salt applied to the test area. At all times except during the most severe temperatures, runoff flows were in excess of 0.1 cfs(41,42). When highway salts were not being applied, the chloride content of drainage varied from 1,900 to 4,500 mg/l, and runoff was as high as 0.3 cfs. During snowfalls, the chloride in highway runoff ranged from 11,000 to 25,000 mg/l, and the flows varied from 0.1 to 1.5 cfs. This study further indicates that nearly all the deicing salts subsequently left the area in the form of runoff.

The APWA study in Chicago also calculated that a chloride level of 1,300 mg/l could be expected in the runoff, assuming 1.5 tons of salt are applied per mile of two-lane highway for each inch of snowfall(41). In comparison to these figures, the 1970 Highway Research Board literature review(5) determined that 600 lbs. of salt per mile if applied to a 20 foot wide road with 0.2 inches of ice at 25°F will produce an initial salt solution of about 69,000 mg/l; at 10°F, the resulting salt solution will be around 200,000 mg/l. These saturated solutions will of course become more dilute as melting of the snow and ice continues. Considering these values, it is not surprising to see various references citing several thousand parts per million salt being carried in highway runoff. The salt content of highway drainage will depend upon many factors including ambient temperature, amounts of precipitation, quantity of salt applied, traffic patterns, and volume and rate of surface flow.

Sullivan(41) recognizes that wintertime highway runoff will eventually run into freshwater streams and natural or man-made lakes or ponding areas. He cautions that unless there is adequate dilution, the salt concentration in street runoff may in the future have adverse effects upon fish life or vegetation. The suggestion is made that "monitoring of such storm areas should be carried on at various depths to detect significant changes in concentration". Secondly it is advised..."if a chloride balance is to be maintained in a river to limit chloride to an acceptable level for potable water supplies, (then) the runoff from urban areas must be accounted for and allowances made in the discharge rates (permitted) from industrial plants at the time of any low winter flows."

Des Moines, Iowa

Henningson, Durham and Richardson, Inc. recently completed a detailed study for the FWQA on combined sewer overflows and stormwater runoff in the city of Des Moines, Iowa(43). Part of the program was directed to characterization of wintertime runoff, and chloride data were collected from a number of combined sewers and storm drains over the period of December 1968 through March 1969. The drainage areas are largely residential and there are no large concentrations of commercial and business establishments where exceptionally heavy street salting may be expected. The Des Moines area experienced a relatively severe winter in 1968-1969 and quantities of road deicing materials used from

December 1968 through March 1969 approximated 9,270 tons untreated rock salt, 295 tons of calcium chloride and 225 tons of rock salt treated with a rust inhibitor. Total deicers used were 9800 tons, with a chloride equivalent of 5830 tons.

The Thompson Avenue storm drain serves an area of 315 acres classified mainly as residential. Results for this storm drain showed that approximately 15,000 pounds of chlorides were carried off in the runoff from January 15 to March 2, 1969, which approximates 48 pounds per acre. The study indicates: 1) although appreciable snow and sleet, and heavy salt applications occurred prior to January 15; 2) little snowmelt had taken place before mid-January but nevertheless; 3) much of the salt applied before January 15 was no longer on the streets. Four discrete snowmelt periods provided the following data for the Thompson Avenue drainage area:

January 15-16, 1969	0.236 inches runoff	3.75 lbs. Cl ⁻ /Acre
February 4, 1969	0.049 inches runoff	11.80 lbs. Cl ⁻ /Acre
February 5, 1969	0.038 inches runoff	3.52 lbs. Cl ⁻ /Acre
February 25, 1969	0.149 inches runoff	<u>1.63 lbs. Cl⁻/Acre</u>
Total =		20.7 lbs. Cl ⁻ /Acre

Sequential sampling illustrates that chloride levels are highest at the beginning of runoff and concentrations decrease rapidly thereafter. Individual results for the Thompson Avenue storm drain ranged from a low of 9 mg/l chlorides on January 17, 1969 to a maximum of 2,320 mg/l on February 21, 1969. Typical data for individual samples collected on February 4-5, 1969 are given below(43).

February 4, 1969	2:15 PM	Flow - 3.9 cfs	1477 mg/l Cl ⁻
February 4, 1969	3:15 PM	Flow - 3.7 cfs	1228 mg/l Cl ⁻
February 4, 1969	4:15 PM	Flow - 2.5 cfs	1045 mg/l Cl ⁻
February 4, 1969	5:15 PM	Flow - 1.1 cfs	920 mg/l Cl ⁻
February 5, 1969	12:15 PM	Flow - 0.2 cfs	743 mg/l Cl ⁻
February 5, 1969	1:15 PM	Flow - 1.5 cfs	260 mg/l Cl ⁻
February 5, 1969	3:15 PM	Flow - 3.1 cfs	579 mg/l Cl ⁻
February 5, 1969	4:15 PM	Flow - 2.5 cfs	502 mg/l Cl ⁻

Salt levels in the runoff collected from the Cummins Parkway storm drain, serving a predominately new residential area of 356 acres, demonstrated patterns similar to the Thompson Avenue storm drain(43). Periods of snowmelt produced high chloride concentrations and the range of individual results varied from 18 mg/l on January 16, 1969 to a maximum of 2,720 mg/l on February 21, 1969. Measured flows in the Cummins Parkway drain varied from 0.0 to 47.9 cfs compared to 0.0 to 9.9 cfs for the Thompson Avenue storm drain. In the combined sewer systems, a maximum chloride concentration of 866 mg/l was found in the South Side Trunk sewer on February 4, 1969.

Henningson, Durham and Richardson also collected wintertime samples from the Des Moines River and Raccoon River above and below the city of Des Moines starting January 1969. The report(43) concludes that chloride levels in the river waters were significantly higher in the winter months than in the summer. In January and February, chlorides were around 30-50 mg/l for the locations upstream of Des Moines, and the highest result was 56 mg/l. Downstream of Des Moines, the chlorides commonly exceeded 56 mg/l and the maximum level was 86 mg/l. During the spring and summer months, the chlorides throughout the area were below 20 mg/l, but as stream flow diminished in the autumn, the chlorides increased to between 20-30 mg/l.

SECTION VII

SURFACE STREAMS, RIVERS

Various Rivers in the State of Maine

Hutchinson(44,45,46,47,48) analyzed seven major rivers in Maine for sodium and chloride levels over the period 1965-1967. These ions were generally 1-2 mg/l at the headwaters and increased to as high as 15-18 mg/l at the mouths of the respective rivers. Highest levels of sodium and chloride were shown in the southern section of the State where highway miles were greatest, but other factors also were present. Based upon these data, Hutchinson concluded at least at that time, no adverse effects of highway salting upon river water quality could be shown.

Hutchinson sampled the Kenduskeag Stream in the Bangor, Maine area both upstream and downstream of the city, together with two storm drains and a brook entering into Kenduskeag Stream. Also included in this study was a culvert carrying surface drainage from one mile of Interstate Highway 95. The survey was conducted for 60 consecutive days from March 1 to April 29, 1966. The upstream waters of Kenduskeag Stream contained sodium and chloride levels of 3.9 mg/l and 6.5 mg/l, respectively. Downstream of the storm drains and the brook, the Kenduskeag Stream through the center of the city showed average sodium and chloride levels of 5.3 and 10.0 mg/l, respectively. The two storm drains contained runoff with average sodium content of 26.8-28.8 mg/l and average chlorides of 73.9-84.6 mg/l. The highway culvert exhibited the highest level of sodium and chloride with mean values of 168 mg/l and 570 mg/l, respectively. Hutchinson concludes since there was little industrial pollution in the area, it appears safe to consider that "road salt contamination" was significant in these waters. Although it was apparent that sodium and chloride levels in the Kenduskeag Stream are definitely affected by surface drainage from the city of Bangor, the salt concentrations downstream remain low because of considerable dilution in the stream(44,45,46).

Meadow Brook, Syracuse, New York

The surface waters of Meadow Brook watershed in southeastern Syracuse, New York, have been studied by Hawkins(40) from October 1969 through the present. Meadow Brook drains about four square miles of suburban Syracuse, described as approximately two-thirds developed land, which receives heavy annual snowfall as well as moderate residential traffic. From past results, Hawkins found a large variation in mineral content of the Brook, particularly chloride concentrations. From late-November to mid-March, chlorides were usually in the range of 200-1,000 mg/l, but frequently exceeded a few thousand mg/l. For example, a sample in December 1969 showed about 11,000 mg/l chlorides. Over the remaining

months of the year, chlorides were relatively low and in the range of 30-150 mg/l. Hawkins more or less concludes that: 1) salt runoff from the watershed is discharged in several high concentration surges during the winter and melt season; 2) salt concentration in the stream is a function of available snow and salt and the prevailing temperatures; 3) chlorides diminish through the spring and summer but still remain suspiciously high, suggesting some retention in the watershed and the contribution of this salt to summertime base flows; and 4) a close correlation indeed exists between road salting and stream chlorides(40).

Major Rivers in the United States

Effects of highway salts upon major rivers in the U.S. appear small compared to other sources. Chloride content of major rivers are relatively low compared to wintertime road runoff and ditch drainage. Unfortunately, adequate data does not exist on sodium and chloride levels for most rivers of the northeast and north-central U.S. Heavy snowmelt will also coincide with the start of rising streams during late winter and early spring, making it difficult to distinguish road salts. Nevertheless from the limited data available on streams, increasing chloride trends are evident for some of the large rivers in the U.S. Highest salt loads are generally present in these streams from the end of February to the end of May(5).

Hanes et. al., in their 1970 report for the Highway Research Board(5), utilized chloride curves for major rivers in the U.S. based upon Public Health Service water quality monitoring data over the Water Years of 1958-1963. The amounts of chlorides in terms of mg/l and tons/day were plotted for the Delaware River near Philadelphia; the Hudson River below Poughkeepsie, N.Y.; the Mississippi River at East St. Louis, Ill.; the Missouri River at Kansas City, Kansas; the Ohio River at Cairo, Illinois; and the Potomac River at Great Falls, Md. Chloride concentrations in these curves did not vary greatly throughout the year, and in all but one case were below 35 mg/l. Only the Hudson River and the Ohio River showed increase in chloride levels during the February-May period. However, the report concludes the chloride levels are clearly increasing from year to year in the Hudson River and the Delaware, and even though present levels are low,..."this increase could be a potential danger"(5). It is recognized that other factors such as sea water intrusion and cyclic patterns may be present in this 1958-1963 data.

Sleepers River Basin, Vermont; Hydrologic Salt Balance

Kunkle(49) provided annual salt budgets for the Sleepers River basin in northeastern Vermont from 1968-1970. A 2.5 mile section of U.S. Highway 2 traverses one of the watersheds in this basin, which receives heavy traffic and large amounts of deicing salt in the wintertime. The various watersheds not influenced by the highway showed streamflow chloride levels of only 2-5 mg/l. However, sampling stations downstream of the highway

were typically an order of magnitude higher. Due to high runoff per unit area in the watersheds, excessive salt concentrations in the watercourse proximate to the highway were appreciably diluted a few miles downstream. Chloride levels were highest in the summertime baseflow of the highway watershed. Some of the deicing salt apparently entered into the soils near the road and later appeared in the summer flows. Individual seeps sampled close to the highway showed chlorides in excess of 200 mg/l.

The Vermont study showed that stream salt concentrations were lowest in the springtime due to considerable dilution. Nevertheless, during spring thaws, much of the salt from the highway was being flushed from the highway to the stream, and salt delivery rates (in tons/day) were highest at this time of the year. On the other hand, the control stations demonstrated little seasonal fluctuation in salt delivery rates. Sodium chloride yields for the control watersheds averaged about 1 tons/square mile/year. Subsequent calculations for the highway watershed yielded about 83 tons/year of sodium chloride in excess of background amounts. From highway department records, observations and other field data, Kunkle estimated that 65 to 100 tons salt were applied annually to the highway section in the watershed. It therefore appears the large majority of highway deicers eventually entered into the surface streams(49).

The older reports in the literature indicate that about one-half of deicing salts applied onto highways are usually discharged with the runoff, and about one-half is retained within the area. However, the Vermont study given above, the results previously cited by the American Public Works Association for the Kennedy Expressway in Chicago (see Section VI), and likewise the assumptions made by O'Conner and Mueller in estimating road salt inputs to the Great Lakes (see Section VIII), strongly imply that the large majority of these salts over a sufficient period of time, may find their way into downstream surface waters. Additional studies providing material balances over defined intervals of time and of sufficient duration, would be extremely useful in assessing the fate and behavior of deicing salts previously applied to roads and highways. Such studies could also lead to a proper understanding and application of methods whereby salt sensitive areas could be protected, and promising salt recovery/reuse techniques utilized.

Chloride Levels in Milwaukee Streams

High concentrations of chlorides in various river waters in the Milwaukee area during mid-January 1969 were previously given in Section V of this report.

Oxygen Demand of Deicers

Schraufnagel, in discussing substitute deicing compounds, describes the glycols and alcohols in particular, as having extremely high biochemical oxygen demand (BOD), ranging from 70 to 133 percent of the product

weight(18). In contrast, urea has a 5-day BOD:weight ratio of only 9 percent and sewage only 0.02 percent. Schraufnagel makes the point that certain deicers, such as ethylene glycol, if released into a nearby stream can exert tremendous demand on existing dissolved oxygen. It is indicated that one pound of deicing compound with a BOD:weight ratio of 1.0, if discharged into a waterway having 7 mg/l dissolved oxygen, will utilize all the oxygen available in about 140,000 pounds (17,000 gallons) of streamflow(18).

Dumping of Snow Into Nearby Streams and Water Bodies; Chloride, Oil and Lead Content

Following the plowing, sanding and/or salting of streets and highways, significant accumulations of snow, slush or ice are often collected into receiving trucks and transferred to outlying areas for final disposal. Frequently these large volumes of snow are deposited or dumped into the nearby stream, into a bay or river (see Figure 18), or onto the banks of a water supply reservoir. Most cities indicate they have discontinued such disposal practices. Nevertheless, they continue to deposit this snow onto areas lying within the flood plains or higher lands leading directly into a waterway. Realistically, the latter means of disposal is no more acceptable than direct dumping into the stream.

Data is generally lacking on the chemical makeup of snowfall after becoming impregnated with deicing salts; oils, greases and dirt from vehicular traffic; and other urban wastes. Data given previously in this report show maximum chloride levels of up to 10,000 mg/l in a typical snowbank along the highway. Studies in Stockholm, Sweden(50) indicate during their normal winters, about 1,100,000 cubic yards (30×10^6 cubic feet) of snow from city streets are dumped. Unmelted snow from selected street locations in Stockholm were found to contain 2-105 mg/l oils and 1-100 mg/l metallic lead. Median values were respectively, 21 and 18 mg/l. The oil and lead in snowfall were reported to be related in this study to vehicular traffic, particularly the unburned gasoline and the components of tetraethyl lead condensates spread onto the cold snow surfaces. Additional samples of untouched snowfall from one of the Stockholm parks interestingly enough showed as much as one mg/l oil as well as traces of lead.

The high lead content found in snowfall in Sweden is supported by recent information from Columbus, Ohio(51). Snow collected from streets in Columbus, Ohio, contained "about 15 times more lead than the safe limit set for drinking water by the Public Health Service." Samples taken at locations distant from city roads showed lower concentrations suggesting that motor vehicle exhaust is a major factor contributing to this lead. The best means of removal and ultimate disposal of excess snow, slush and ice from urban centers, deserves careful attention and considerable research in the future.

SECTION VIII

FARM PONDS, LAKES

Farm Ponds-State of Maine

Twenty-seven farm ponds located along various highways in Maine, were sampled by Hutchinson in April, July and August, 1966-1968. The April samples were significantly higher in both sodium and chloride content compared to the summer collections. Sodium levels ranged from 1 to 121 mg/l with an average of 33 mg/l. The chloride range was 1-490 mg/l, and average levels were 110 mg/l for April and 80 mg/l for August. Normal chloride levels for farm ponds in this geographic area are 5-10 mg/l. It was concluded that road salts have significant seasonal influence on chloride content of farm ponds, and that repeated yearly salting is steadily increasing the salt levels in some of these ponds(5,41,45,52).

The Great Lakes, Lake Erie

Long-term studies of Lake Erie have shown that average chloride content has increased three-fold in the last 50 years, from 7 mg/l in 1910 to about 23 mg/l in 1964. Although it is reported that present uses are not adversely affected, a continued rate of chloride buildup could cause serious impairment of water uses in the future. Highway salts are estimated to contribute 11 percent of the total annual input of chlorides into Lake Erie waters(5,53). Road salts entering Lake Erie on an annual basis were estimated by O'Conner and Mueller(38) to be 750,000 tons in 1960. Similar estimates of road salt inputs for Lake Superior, Michigan, Huron and Ontario were respectively 91,000 tons; 438,000 tons; 198,000 tons, and 525,000 tons(38).

Wisconsin

The State of Wisconsin and other public authorities have maintained a long-term monitoring program on the quality of various lake waters in the Madison, Wisconsin area. One of the smaller lakes in the area is Lake Wingra, which is spring-fed, but which also receives runoff from nearby streets and urban lands. Through 1940-1947, average chlorides in Lake Wingra were 4-5 mg/l. In March 1959, the chloride content of the lake had increased to 18 mg/l, but in July of the same year the chlorides had stabilized to between 9-11 mg/l measured from top to bottom in the lake. Concern was expressed when subsequent sampling of lake waters in the summer of 1965 showed chloride concentrations of 41-43 mg/l. Although existing water uses apparently are not affected by current water quality, chlorides have increased four-fold since 1959 and eight-fold since the 1940-1947 period(9).

Also in Wisconsin, samples taken in the winter of 1959 from Beaver Dam Lake at Cumberland, Wisconsin, showed a density stratification of chlorides with lake depth. The chloride concentration was 8 mg/l near the lake surface, and 33 mg/l at the 15-foot depth near the lake bottom. Schraufnagel suggests this chemical stratification is due to highway runoff entering Beaver Dam Lake(9).

First Sister Lake, Ann Arbor, Michigan;
Salt-Induced Stratification

Judd in 1965-1968 studied the impact of highway salt runoff on First Sister Lake, a small body of water surrounded by a residential subdivision, an interstate highway and other well-travelled roads in the Ann Arbor, Michigan area(54). Storm runoff from adjacent streets and roads enters First Sister Lake mostly through storm sewers. The lake is approximately 450 feet by 650 feet with a maximum depth of about 25 feet, and the lake has a single outlet used only for about 1-2 weeks in the spring.

Judd found the salt flows moving through First Sister Lake have the tendency to sink to lower depths causing density stratification of the waters. With normal snowfall and road salting, the levels of salt in the lake create sufficient stratification to preclude complete wind mixing of the lake in the spring. Chloride concentrations at the 23-foot depth were around 150 mg/l compared to 60-85 mg/l in the surface waters. Through the summer, some of the salts eventually find their way into the bottom muds, and lake stability^{1/} is lowered to enable complete mixing of the waters in the fall months. If salts had not been absorbed into the bottom muds, it is speculated there would be no lake overturn not only in the spring but also in the fall. This stratification is associated with extended periods of low dissolved oxygen in the deeper waters, and detrimental changes in animal and plant life in the lake. Even assuming previous fall overturn, Judd indicates through 1967, the deeper zones of the lake were likely without oxygen for some ten months, and the entire lake below the 10-foot depth was virtually devoid of dissolved oxygen for about eight months(54).

Irondequoit Bay, Rochester, New York;
Salt-Induced Stratification

Recent studies by Diment and Bubeck in 1969-1970 for the Irondequoit Bay drainage basin near Rochester, New York, show that salt runoff has markedly affected the water quality within the Bay(57). The basin has a relatively dense population with total population around 210,000 persons. Irondequoit Bay is fed by Irondequoit Creek and empties into Lake Ontario via one narrow channel. The water body is approximately 3.7 miles long by 1 mile wide, with average and maximum depths of 24 feet and 75 feet,

^{1/} "Stability" of a lake is defined by Schmidt(55,56), as the amount of work required to mix the total body of water to uniform temperature without adding or subtracting heat.

respectively. During the winter of 1969-1970, highway salts were applied to basin streets at the rate of 85,000 tons. These deicers are reported as the single major source of salt into the Bay.

Diment and Bubeck describe Irondequoit Bay as a striking example of salt accumulation. Approximately two-thirds of the yearly salt input enters the Bay from December through March. For 1970, the average chlorides in the surface waters of the Bay were about 160 mg/l, compared to an average of 320 mg/l chlorides contained in the incoming wintertime flows, 1969-1970. Except during fall overturn, chlorides in the bottom waters of the Bay were 220 to 400 mg/l. From January to November 1970, intense physical and chemical stratification prevailed, and the bottom waters showed no more than 1 mg/l dissolved oxygen. Overall results showed of the 85,000 tons of deicing salts introduced in the basin, some 35,000 tons left in the lake outflows. Therefore, more than one-half of these salts were retained in the soils and groundwaters of the basin and in the Bay muds(57).

Diment and Bubeck conclude that winter influx of salt into Irondequoit Bay causes significant differential in vertical density, which is sufficient to prevent the Bay waters from completely mixing in the spring. During 1939-1940, the only previous period for which comparable data were available, the Bay exhibited normal tendencies of a typical deep lake in a temperate continental climate with stratification and complete mixing both in the spring and fall. Apparently the lack of spring mixing is not unusual for very small, deep lakes, but is rare for a lake as large and shallow as Irondequoit Bay. The above changes are not viewed with serious alarm by the investigators, but nevertheless, salt runoff has convincingly modified the characteristics of the Bay. Similar conditions could occur elsewhere. The rising chloride levels also imply the need for careful monitoring of water quality conditions in the Irondequoit Bay drainage basin, and that serious consideration be given to the local distribution and storage of deicing salts in the groundwaters(57).

Possible Salt Stimulation of Algal Growths

A new development in salt pollution concerns the potential role of sodium serving as a trace element toward stimulating excessive growth of blue-green algae. Recent data indicate in addition to nitrogen and phosphorous, adequate amounts of sodium and potassium may also need to be present for the growth of blue-green algae. Certain blue-green species may require one of these monovalent elements, whereas other species may require both. One reference states that sodium concentrations greater than 40 mg/l may be necessary for triggering undue growth of blue-greens. Another reference infers that 5 mg/l of sodium provides for optimum growth of *Anabaena cylindrica*, which is common in nuisance algal blooms. Further investigation is essential on the suspected relationship between eutrophication and sodium buildup from deicing salts(58,59).

SECTION IX

WILDLIFE

Over the winter of 1958-1959, a number of wildlife mortalities in Wisconsin were attributed to salt poisoning caused by highway deicing chemicals(9). Within a 40-mile radius of Madison, Wisconsin, cases of salt poisoning were diagnosed in wild rabbits, pheasants, a quail and a pigeon. Although the gizzard contents of the dead quail were stained blue with ferric ferrocyanide, which is a common additive in highway salts, the additive was not implicated as the cause of death. As part of their follow-up studies, the State of Wisconsin experimentally induced single doses of 3 grams sodium chloride into test animals including adult pheasants and rabbits weighing 1100 to 1400 grams each (454 grams = one pound). This dosage generally produced death in the animals within 24 hours, and mortality was highest when water intake was restricted. Heavy snows and cold weather in the winter of 1958-1959 likely contributed to this problem by reducing food and drinking water available to the animals, and in turn creating "salt hunger" conditions. It should be noted that the literature source for the above study does not provide ample description on the particular test procedures used(9). Hanes et. al.,(5) also express some reservations concerning these results. Animal husbandry practices in the midwest and western U.S. often provide wild animals such as deer with free access to "salt licks" in the wintertime. Apparently this question has not been fully resolved.

Hanes et. al.,(5) consider ungulate animals being attracted onto highways in their search for salt, to constitute a much greater hazard not only to the animals, but to motorists alike. In the State of Wisconsin, approximately 120,000 deer are killed annually, the large majority by hunters. However, State personnel estimate that nearly 12,000 deer or 10 percent of the total, are killed along Wisconsin highways by motorists(60). The frequency of this type of accident appears much higher in the wintertime when large amounts of deicing salts are left remaining on the highway.

SECTION X

DEICING ADDITIVES

Special substances may be added to sodium chloride and calcium chloride to reduce corrosion, or for reasons of better efficiency in handling and applying deicing salts. Materials such as Prussian blue, sodium ferrocyanide (yellow prussiate of soda), chromates, phosphates, etc., are listed in the literature as available for use. The manufacturer recommends these agents be added in the amounts of 0.5 to 2 pounds or more, per ton of deicing salt(5).

Ferric and Sodium Ferrocyanide, Anti-Caking Agents

The two most common additives to highway salts are ferric ferrocyanide (Prussian blue) and sodium ferrocyanide, both used as anti-caking agents. Ferric ferrocyanide is relatively insoluble in water, and according to various reports will not release cyanide upon acidification. Laboratory tests by the Wisconsin State Laboratory found that blunt-nose minnows do not appear adversely affected when placed into a 9600 mg/l concentration of Prussian blue for 48 hours(9).

Sodium ferrocyanide, unlike Prussian blue, is soluble in water and will liberate cyanide in the presence of sunlight. The cyanide ions are far more lethal to fish and aquatic life than the sodium ferrocyanide. The cyanide ion will react with hydrogen in water to form hydrogen cyanide. The dissociation of hydrogen cyanide is pH-dependent. At pH 7 or below, only one percent of the hydrogen cyanide will exist as the cyanide ion, whereas at pH 9, the cyanide ion will comprise 42 percent of the total(5). Studies on sodium ferrocyanide show toxic levels for *Daphnia magna* at less than 600 mg/l(61), and 540 mg/l(62). A toxic threshold of 170 mg/l sodium ferrocyanide has been found for *Polycelis nigra*(63). Subsequent tests conducted by the Wisconsin State Laboratory determined that a 15.5 mg/l solution of sodium ferrocyanide, if exposed to sunlight for 30 minutes, would produce 3.8 mg/l of cyanide. With increased exposure time, this level of cyanide remains fairly constant. Since a similar solution of sodium ferrocyanide in the dark produces relatively little cyanide in solution, this reaction is considered light-sensitive, i.e., photochemically-induced(5,9).

Comparable test results may be obtained using potassium rather than sodium ferrocyanide since chemical reactions of the two chemicals in water are reported to be nearly alike(5,9). Schraufnagel(9), in his report, makes note of the work of Burdick and Lipschuetz in 1948(64) on the toxicity of potassium ferrocyanide and potassium ferricyanide. It was originally thought these two compounds were relatively innocuous to fishlife. However, Burdick and Lipschuetz found that sunlight rapidly decomposed the potassium derivatives to produce cyanide ions toxic to fishlife. With very low light intensity or dark conditions,

4,000 mg/l potassium ferrocyanide was required to generate 0.3 to 0.6 mg/l cyanide which killed 100 percent of the test fish in 48 hours. In contrast, with direct sunlight, 0.36 to 0.48 mg/l cyanide was generated by only 2 mg/l of either potassium ferrocyanide or potassium ferricyanide in solution, sufficient to kill various fish within 60 to 90 minutes(5,64). The potassium compounds as far as known, are not used as salt additives, but should serve to predict similar effects of the sodium ferrocyanide in receiving waters.

Schraufnagel(9,65) comments that cyanides are toxic to fishlife at concentrations of 0.1 to 0.3 mg/l. The U.S. Public Health Service Drinking Water Standards of 1962(66) state that levels of cyanide above 0.2 mg/l would constitute grounds for rejection of a public water supply. The 1969 U.S. Public Health Service "Manual for Evaluating Drinking Water Supplies"(67) further indicates that cyanide in municipal supplies should not exceed 0.01 mg/l. However it should be noted this manual is primarily intended as a guide in evaluating these systems and not as a requirement for approval or rejection of any public water supply. Pertinent data in unpublished guidelines(68) also suggest the following objectives: desirable and permissible cyanide limits in public water supplies - respectively 0.01 mg/l and 0.1 mg/l; and for body contact recreation, fisheries use and farmstead supply - a limit of 0.02 mg/l cyanide. Numerical limits for cyanide are among the lowest and most critical of all the trace ions to be tolerated for various water uses. The literature is fairly generous in giving data on whole body dosages of cyanide and hydrogen cyanide considered toxic to man(5,62,69,70,71,72), and to domestic animals(5,62,73). Additional references are available on toxicity of cyanides to fish, and effects of temperature, dissolved oxygen and chlorination on varying toxicity(5,62,65,74,75,76,77,78,79,80).

Schraufnagel(9) has calculated "if sodium ferrocyanide were used...at a rate of 2 pounds per ton of salt and...the amount of cyanide released is equal to about one-fourth the additive's concentration, an 800 mg/l concentration of rock-salt deicer would present a hazard to fish life and water supplies because of the accompanying cyanide. This is equivalent to about 500 mg/l of chloride, a value which is frequently exceeded in road runoff, but to our knowledge has not been exceeded in surface waters..." Chloride levels exceeding 500 mg/l were however obtained for the Kinnickinnic, Menomonee and Milwaukee River waters in January 1969 in the Milwaukee area, as previously cited in Section V of this report. Schraufnagel also estimates that between one-half to two-thirds of all rock salt used for deicing in the State of Wisconsin is specially treated with anti-cake agents.

Recent information(11) indicates that the amounts of sodium ferrocyanide added to salt stocks have somewhat decreased over the past few years. The salt industry as of May 1971, cites the figure of 0.5 pounds sodium ferrocyanide ten-hydrate added per each ton of rock salt, although it is thought this figure does not necessarily apply to all deicing salts sold across the country. The industry contends that no environmental hazards are caused by the cyanide additives. Nevertheless, the conclu-

sions and recommendations given in this report concerning these additives are considered highly appropriate and valid, not only because of the serious nature of cyanides but also due to an absence of field data on the prevailing level and fate of these additives in the environment.

Corrosion Inhibitors

Special additives are available for reducing the levels of corrosion and rusting associated with highway salts. Unfortunately, only fragmentary data exists on past and present use of these additives, their costs, and proven effectiveness in minimizing corrosion. It is believed that past use of corrosion inhibitors has been significant. Three products in particular have received greatest attention: a) a chromium-base inhibitor used in the 1950's but apparently later discontinued; b) a sodium hexametaphosphate product manufactured by Calgon, Incorporated; and c) a product introduced by Cargill, Incorporated around 1964, which consists of chromate salts mixed with an organic inhibitor, emulsifier and sodium chloride(5,9,81).

Chromate Additives Used As Rust Inhibitors

In Michigan during the winter of 1955-1956, a chromium-base rust inhibitor had been used with calcium chloride for highway deicing. In one area of Michigan, however, there was great concern because snowpiles alongside the road were yellow in color. Fortunately, local personnel quickly recognized the possible danger of chromium entering into the nearby groundwater supplies and stopped all further use of the chromium-treated salt(82). In other parts of the country on certain occasions, streets and highways have also turned blue, green, or yellow following heavy road salting.

The U.S. Public Health Service Drinking Water Standards of 1962(66) state that a concentration of 0.05 mg/l hexavalent chromium provides sufficient grounds for rejection of a public water supply. Pertinent data contained in unpublished guidelines(68) also suggest the following objectives: desirable and permissible hexavalent chromium limits in public water supplies - respectively 0.02 mg/l and 0.05 mg/l; for farmstead supply - a limit of 0.05 mg/l; and for body contact recreation and fisheries use - a limit of 1.0 mg/l.

Although relatively stringent limits have been placed on hexavalent chromium, particularly for drinking water, the carcinogenic potential of hexavalent chromium is good reason to preclude its entry into a potable water supply(83). Trivalent chromium generally is not considered physiologically harmful, and the U.S. Public Health Service Standards do not place specific limits on this constituent. However, trivalent chromium has been occasionally found more toxic than the hexavalent ion to some aquatic plants and animals including *Daphnia magna*(65).

Numerous references are given in the literature for effects of hexavalent and trivalent chromium on biological sewage treatment processes and sludge digestion. The trivalent form of chromium is fairly easily oxidized to the hexavalent form, whereas the reaction may be reversed under the influence of heat, presence of organic matter or reducing agents. Toxicity of chromium ions to bacteria is governed by many variables. Under aerobic conditions, the toxicity of the trivalent ion is generally higher than hexavalent chromium. In the absence of oxygen, the oxidized form if present, is considered far more toxic to bacteria(65).

The Cargill report in describing its 1965-1967 studies(81), assigned toxicity ratings to each of the major ingredients found in its deicing product. Since chromate salts comprised a small percent of the total product, the manufacturer indicated that sodium chloride (major component in the product) "is really the critical toxic ingredient in this formation and not the chromate salts". This report described studies conducted in Winnipeg, Canada where 1-3 percent (10,000 to 30,000 mg/l) sodium chloride was found in puddles after highway salting. Cargill calculated "this would be equivalent to 40-120 mg/l sodium chromate"(81). Considerable sampling was undertaken in the Minneapolis-St. Paul area of storm sewer flows, streams and rivers principally during the winter of 1965-1966 and again in 1967. Samples were analyzed for trivalent, hexavalent and total chromium and chloride content.

From December 1965 to February 28, 1966, the consumption of Carguard (Cargill) salt in Minneapolis was 13,258 tons. Samples of December 29 taken of street runoff in Minnetonka Village, Minneapolis, showed a salt concentration of 1.1 percent (11,000 mg/l) together with 24 mg/l of sodium chromate. From various sewers in the Minneapolis-St. Paul area, many values of hexavalent chromium and trivalent chromium were reported in the range of 0.3 - 0.8 mg/l; and maximum values were 1.7 mg/l hexavalent chromium, 2.2 mg/l trivalent chromium and 3.9 mg/l total chromium. These chromium concentrations were considerably above desired levels. For surface water samples, Cargill indicated none exceeded 0.05 mg/l hexavalent chromium. The chloride results for wintertime sewage flows in the Minneapolis-St. Paul area (presumably both storm and combined sewers) showed high chloride concentrations as follows: Bridal Veil Falls Sewer (Minneapolis), January 22, 1967 - 2590 mg/l, February 24, 1966 - 3050 mg/l, February 28, 1966 - 1060 mg/l; Broadway Sewer (St. Paul), February 8, 1966 - 2670 mg/l; and Smith West Sewer (St. Paul), February 8, 1966 - 720 mg/l, January 22, 1967 - 2520 mg/l, March 20, 1967 - 1610 mg/l(81).

The Henningson, Durham and Richardson study recently conducted for the FWQA on combined sewer overflows and stormwater runoff in the city of Des Moines, Iowa, provided certain data on effects of highway salts on street runoff(43). Chloride results obtained from the HDR study are previously described in Section VI of this report. Although considerable highway salts were used in Des Moines during the winter of 1968-1969, only a small quantity of chromium - treated salt was deployed over the study area. Various samples taken from two drainage systems containing

combined sewage and storm water, showed that total chromium content was below 0.1 mg/l in all but one sample. The latter sample contained 0.13 mg/l chromium. It was presumed all chromium values in the Des Moines report were given in terms of total chromium. For two storm sewers, specifically the Thompson Avenue and the 20th Street storm drains, street runoff contained less than 0.2 mg/l chromium in all but one sample. Only within the Cummins Parkway storm system were chromium levels significant. Snowmelt runoff in this storm drain routinely showed chromium in the range of 0.1 to 0.3 mg/l during January-March 1969, and three samples had chromium levels of 0.35, 0.88, and 1.21 mg/l(43).

Information recently provided by the Salt Institute(11) states that the single reported supplier of chromium-treated salt, has in the past few months, discontinued the sale of its product. The results given in this report on the use of chromium additives with road salt and the levels of chromium found in the environment, nonetheless, are considered highly pertinent. These results reflect the fact that chromium additives have been deployed over a long period of time and probably were supplied from many different sources. The chromium-treated salt cited above was taken off the market because cost overshadowed its effectiveness as a corrosion inhibitor, and not principally due to environmental considerations. The effects of past use of chromium additives may still be present in soils and groundwaters, but more importantly, there is no guarantee that these compounds are no longer being used and will not be used in the future. Rather than discount the importance of chromium, environmentalists should be aware that rapid changes are possible also in the deicing industry. Such changes could lead to new products and additives, which in turn could either minimize or further intensify the pollution problems caused by highway deicing.

Phosphate Additives Used As Rust Inhibitors

Another corrosion inhibitor commonly mixed with highway salts is sodium hexametaphosphate. This type of rust preventative is probably best exemplified by the product, Banox, manufactured by Calgon, Inc. which contains sodium hexametaphosphate as the effective ingredient(5,9). Schraufnagel(9) in 1966, indicated that Banox mixed with salt would represent an additional cost of \$3.00 to \$4.50 per ton of salt. Other reports(5,9) emphasize this product may represent an effective nutrient source and contribute to eutrophication in surface waters, particularly lakes and ponds. Sawyer in 1947(84) showed prolific growth of algae in lakes when the average concentration of inorganic phosphorous was greater than 0.01 mg/l, and Curry and Wilson(85) suggest that 0.01 mg/l of phosphorous is the maximum value permitted without producing undesirable biological growths(5). Schraufnagel calculates if this additive is mixed with salt at a one percent ratio, the resulting street runoff will contain about one part of phosphate for each 200 parts of chloride. Schraufnagel also speculates if all chlorides applied in Dane County, Wisconsin during the winter of 1965-1966 had been so treated, the total phosphate would have been equivalent to the phosphate discharged by the

Madison, Wisconsin sewage treatment plant over a two-month period of time(9).

Smith(86) clearly points out the danger of salt additives in that they may be extremely toxic, especially to fishlife, and produce a variety of objectionable side effects such as encouraging algal growth. Smith infers that any chemical proposed for use as a salt additive should be very carefully evaluated for the extent of any and all detrimental effects.

SECTION XI

PUBLIC WATER SUPPLIES, GROUNDWATER, INDUSTRIAL WATER USES

Public Water Supplies

Public water supplies in both the States of Wisconsin and New Jersey have fairly low chloride content(5). Of 471 water supplies in Wisconsin, the average chloride level is 13 mg/l and the median 7 mg/l. Sixty-six percent of the Wisconsin supplies show 10 mg/l chlorides or less. Of 356 water sources in New Jersey, the average chloride level is 15 mg/l and the median 9 mg/l. Fifty-eight percent of the New Jersey supplies have chlorides of 10 mg/l or less. For the two States, more than 80 percent of the supplies had less than 21 mg/l chlorides, and more than 95 percent had less than 51 mg/l chlorides. However, even relatively low chlorides may adversely affect certain water uses. In Springfield, Massachusetts, following the opening of the Massachusetts Turnpike in 1958, a significant chloride increase was experienced in the city's water supply. Prior to 1958, chloride content was around 2.0 mg/l, which increased to 12.4 mg/l in 1966. Although chlorides were still low, a large industrial water user in Springfield, which requires low electrical conductivity in its supply, indicated difficulty with this water. This municipal water supply thereby, was considered far less desirable for industrial use purposes(4,87).

Groundwater, Well Supplies

The Massachusetts Legislative Research Council Report(4) indicates in general, highway maintenance engineers do not believe road salts are an important cause of groundwater pollution. However, when there is salt contamination of well supplies, the engineers usually place the blame on the runoff from salt storage piles or improper drainage alongside the highway(5). Salt contamination of a secondary water supply along the New York State Thruway was successfully corrected by minor revision of a particular highway drainage ditch(4,5).

Michigan

A 1963 Michigan study showed that roadside runoff containing highway salts, in essence, represented contaminated recharge(82). Roadside wells within the intercepting shallow aquifer in Manistee County receiving such recharge were found highly vulnerable to chloride contamination. One of these wells, 300 feet from a highway department salt pile, contained 4,400 mg/l chlorides. In this case, dissolved salt from the salt storage pile had flowed into a broken section of storm sewer and moved into the groundwater aquifer(5,82). Also in Michigan in Delta County, contamination of shallow parts of the Black River Limestone was caused by salting practices of the

Road Commission. Construction of sheds and tarpaulin coverings were suggested for the salt storage areas to minimize salt leaching and percolation into the water table.

Wisconsin and Illinois

In Wisconsin, five wells were contaminated by salts leaching from a sand-salt stockpile and the well waters ranged from 19 to 1,345 mg/l in chloride content. The local aquifer normally contains less than 12 mg/l chlorides(5,9). Recently in Peoria, Illinois, the city salt storage facility was discovered to be the source of serious chloride pollution to industrial water-use wells along the Illinois River valley(88). It was concluded that this pollution will probably continue for some time even after the salt storage facility has been abandoned unless the salt-saturated earth underlying the storage area is also removed. Rigorous short-term corrective measures are suggested for this area, but nevertheless, it may require several years to purge excessive salts from the aquifer(88).

New Hampshire

The New Hampshire State Highway Department started in 1953 to replace roadside wells adversely affected by chlorides, and this program has increased over the years with 37 wells being replaced in 1964, the last year of reported data. Some of the wells contained in excess of 3,500 mg/l chlorides whereas these groundwaters are normally around 10 mg/l chlorides(5). Most of the problems have been associated with shallow-dug wells and 90 percent of the replacement wells have been of drilled construction. It is reported elsewhere, that up to 1965, the State of New Hampshire had replaced some 200 roadside wells at a total cost of more than \$200,000(18).

Maine

Throughout the State of Maine, from 1966-1968, Hutchinson conducted analyses of 115 wells located along various State highways(44,45,52,89). Samples were taken in April and July-August. Normally sodium and chloride levels are in the range of 3-4 mg/l, but wells adjacent to highways showed average sodium and chlorides around 75 mg/l and 160 mg/l, respectively. One well had 846 mg/l sodium and 3,150 mg/l chlorides. Another well contained 343 mg/l sodium and 1,163 mg/l chlorides. In 1967, about one-half of the wells near a salt-treated road exceeded the chloride level of 250 mg/l. Groundwaters in most cases showed higher chlorides in April compared to summer, indicating a relatively quick response in groundwaters following salt application. It is noted that Hutchinson's contaminated wells were mainly shallow, hand-dug wells. Drilled wells insulated with casing are far less susceptible to salt intrusion.

Hutchinson in his studies in Maine, furthermore found high levels of salt in the snowpiles alongside highways pushed by snowplows as much as 20-30 feet from the edge of the pavement. Maximum sodium and chloride concentrations within a typical snowbank were 713 mg/l and 585 mg/l, respectively. At one site, wind-blown snow was found 60 feet from the edge of the pavement, and also heavily loaded with salt. Based upon these findings, Hutchinson recommends that "private water supplies, wells or ponds, should not be located within a minimum distance of 40 feet from highways because of possible contamination by salt ions". He also suggests certain management practices can serve to partially alleviate the salt problem, e.g., providing intercepting surface drains at the edge of the roadway and chemical treatment of affected soils(44, 45,52,89).

Ohio

At Barbertown, Ohio in 1949-1950, it was found that groundwater on the opposite side of the Tuscarawas River from a salt disposal area contained more than 20,000 mg/l calcium chloride caused by induced infiltration. Groundwater resources could not be developed on either side of the river, and consequently, Barbertown had to close down its entire municipal well field(90,91).

Connecticut

For the State of Connecticut, two cases of water supply contamination caused by highway salts are described by Scheidt(92). Tastes and odors in one municipal water supply were duly noted and attributed to the presence of sodium ferrocyanide (an anti-caking agent) originating from salt storage piles. Recommendations were made that amounts of sodium ferrocyanide mixed with the salt be reduced from 250 ppm to 50 ppm, and that suitable covering be provided for the storage piles to minimize salt penetration into the groundwater aquifer. The other instance involved contamination of groundwater from salt storage piles adversely affecting the well supply serving four families. Excessive salt content not only affected taste and quality of the potable water supply but also was reported responsible for corrosion damage to the plumbing and heating systems. Regarding drainage from salt storage piles, there should be no question that such severe contamination of water supplies must be stopped(92).

Massachusetts

The State of Massachusetts which deploys large amounts of highway salts, due to these deicing compounds, has experienced a wide range of environmental pollution problems. During the winter of 1966-1967, approximately 170,000 tons of sodium chloride and calcium chloride were applied to 9,000 miles of State highways and toll roads in Massachusetts(1). These

figures do not include deicing materials used by the City of Boston and the various counties and towns in the State.

In 1964, the U.S. Geological Survey commenced groundwater sampling along heavily travelled highways located within a 50-mile radius of Boston, Massachusetts. Small diameter observation wells were sunk 19 to 60 feet deep and located 15 to 30 feet off the highway. The study, undertaken in joint cooperation with the Massachusetts Department of Public Works, at the present time comprises more than 40 wells situated within 6 test areas. The highways passing through the test areas include both relatively new and old roadways. The overall objective of the study is to trace the spread of highway salts through roadside soils by means of long-term measurement of vertical and lateral movements(19,93,94). Tentative findings show that a large percentage of the groundwaters are approaching 250 mg/l chlorides, which is the upper limit recommended for public water supplies. The U.S.G.S. investigations, contrary to many previous studies, show a relatively slow movement of salt through the unsaturated zone, then through the groundwater. In one case where the water table was only 2 feet below the ground surface, approximately 12 months lapsed before the salt horizon reached the observation well only 30 feet from the highway. Other lapse times varied from a few months to a few years. Peaks in chloride data generally occur in the period July to December. From these results, as many as 70-80 discrete steps are perceived in downward percolation of salt into the observation well zone. Recharge of groundwater by snow continues through the winter, although at reduced rates compared to the rest of the year. Chlorides are steadily increasing each year. Continuing studies planned beyond 1970 should further define the chloride curves, which could extend beyond the 250 mg/l limit(19).

The Massachusetts Legislative Research Council in 1965(4) reported: "It is well known that both well and surface supplies of drinking water have been affected by increased use of salts". In mid-1964, the Massachusetts Department of Public Health alerted all water supply authorities in the State to the danger of chloride contamination and consequently some water supplies were abandoned. The Department of Public Health described drainage originating from salt storage piles and street runoff as two important sources of hazard. Accordingly, the State Department of Public Works was instructed to cooperate with the Department of Public Health in efforts designed to minimize these conditions(4).

Specific cases of water supply contamination in Massachusetts merit our attention. The town of Becket in 1951 found the water in one of its wells had drastically increased in chloride content to about 1,360 mg/l whereas the other town wells showed a rise in chlorides to about 50 mg/l. These adverse changes were attributed to a salt storage pile located uphill from the well field(95). In recent years, the North Chelmsford Water Commission, through action of the town selectmen, have threatened court action to remove salt stored in a highway garage which was thought to endanger the district well field.

Private and public water supplies in the Weymouth, Braintree, Randolph, Holbrook, Auburn and Springfield areas were among those believed to be affected by highway salts, in Massachusetts. Large salt storage piles located at Routes 128 and 28 in Randolph, and located alongside the Blue Hill River, were suspected of introducing contamination into Great Pond, which serves as water supply for Braintree, Randolph and Holbrook. Water supplies in Tyngsboro and Charlton were similarly experiencing salt increases, and two wells in Charlton were likely to be abandoned(96). Also, in the general Boston area, snow removal and disposal practices are cited as contributing to heavy salt content in the Mystic Lakes(97).

Early in 1970, the Massachusetts Commissioner of Public Health was reported to have given a warning to all physicians and local health boards regarding the care of patients on salt-free diets (specifically sodium-free diets) within salt-affected communities(87). Sodium chloride increases had been recorded in the water supplies of 63 Massachusetts communities at least in part due to highway salting and salt storage piles. Sodium intake must often be restricted for those persons experiencing chronic congestive heart disease, high blood pressure, renal disease, cirrhosis of the liver, and pregnancy(87). The report indicates that persons in normal health will perceive no effects using these water supplies, but adjustment may be necessary for salt-free patients including possible use of bottled water. Many of these communities now have water containing in excess of 20 milligrams salt per quart (21 mg/l), compared to the upper limits of 25-40 milligrams per quart (27-42 mg/l) that are being prescribed for many salt-free patients. The Massachusetts findings are supported by previous guidelines of the American Heart Association(5,98,99), which for people on moderate or strict sodium diets, indicate maximum limits of 20 mg/l sodium permitted in drinking water. The Massachusetts medical alert specifically named the 63 communities so affected(87).

Industrial Water Supplies

On the subject of industrial water use, Schraufnagel(9,18) found that chlorides have been responsible for the corrosion of various metals including stainless steels. Schraufnagel cites a previous recommendation of the Ohio River Valley Water Sanitation Commission that monthly average chloride concentrations in the Ohio River not be permitted to exceed 125 mg/l in order to minimize corrosion of industrial structures. The Ohio River Valley Water Sanitation Commission further recommends that 250 mg/l chlorides not be exceeded at any time to combat corrosion. Schraufnagel also cites an industry statement that "increasing the salinity average above the then 40 to 50 mg/l, or lengthening the periods of high salinity, would increase corrosion of all metals used in the handling system"(9,18).

Although McKee and Wolf in 1963(65), in their extensive review of the literature, found that 50 mg/l chloride generally would not be harmful to industrial water users, they also advise that no "standard" chloride level would be acceptable to meet the demands of all different industrial processes. McKee and Wolf summarize chloride tolerances for various

industries as follows: food canning and freezing - 760 mg/l; carbonated beverages, food equipment washing, and paper manufacturing (Kraft) - 200 to 250 mg/l; steel manufacturing - 175 mg/l; textiles, brewing, and paper manufacturing (soda and sulfate pulp) - 60 to 100 mg/l; dairy processing, photography and sugar production - 20 to 30 mg/l(5,65). Other reviews on water quality needs for industry including chloride limits also are available(100,101).

SECTION XII

CORROSION OF VEHICLES

From the standpoint of the public, there is considerable controversy as to whether highway salts contribute to automobile corrosion. Some critics contend that all rusting on vehicles is due to highway salts. On the other extreme, the statement is frequently made that salts have no harmful effects whatsoever to the finish on cars and trucks. The real situation probably lies between these two extremes. Various changes introduced by automotive manufacturers over the past ten years which include electroplating; deep-dip priming; special paints particularly the acrylic finishes; use of aluminum parts in place of chrome; undercoating; and redesign of trouble-spots where rust occurs, have appreciably reduced this corrosion potential(4). However, at the same time the overall use of highway salts has increased significantly. It is extremely difficult to define potential and existing corrosion due to highway salts because of the lack of reliable and conclusive data in the general literature.

Cost Damages

Besides corrosion of vehicles, airborne salt crystals may be carried onto structural steel, buildings, house sidings and other property alongside streets and highways, causing appreciable corrosion damage to these structures. The amounts of airborne salt may comprise up to 10 percent of the total salt spread during a given storm(4). A rough order of damage magnitude is given in a 1968 report for the Society of Automotive Engineers which indicates "the private car owner pays for rust destruction at the rate of about \$100 a year"(26). Lockwood, et. al.,(6) express little doubt that highway salts contribute substantially to corrosion of vehicles.

How Corrosion Occurs

Various studies have been conducted concerning the corrosive effects of highway salts on car underbodies and the outer decorative surfaces of vehicles. Corrosion commences when the outer paint finish is broken or cracked so that water and/or brine solution comes in contact with the underlying metal. Once corrosion starts it can spread rapidly under the paint film in any direction. The outer finish is forced upward exposing both rusted and new metal which hastens the corrosion process. Breaks in the painted surface are the result of flying gravel, stones, highway debris; blows and scratches particularly on car doors; and poorly fitting parts on a car, e.g., molding strips, trunk lids, etc. Crevices which tend to retain water and brine also make these areas susceptible to attack. Corrosion is caused by atmospheric oxygen combining with exposed metals, especially iron and steel, in the presence of moisture

to produce iron oxide, otherwise known as rust. The literature points out that salt and brine as such, do not cause corrosion(4). Nevertheless, it is well known when the metal is exposed to salt water, the electrolytic reaction converting the metal to its oxide will proceed at a much faster rate compared to water alone(102).

The normal conditions under which an automobile must operate are conducive to maximum potential corrosion of exposed metal surfaces. During the wintertime, vehicles are frequently exposed to salt spray, dirt, grime, etc., and this material accumulates particularly on the underside and lower parts of the car body. Studies in Iowa show for normal application of highway salts, about 50 percent of the salts are removed from the roadway by traffic, 25 percent is carried off by surface water, and about 12 percent leaches through the soil(103). We do not know what part of this 50 percent is retained on the car body. Under such conditions, salt and brine may be responsible for considerable damage to automobiles.

Comparative Studies

Some of the earlier corrosion studies involved large numbers of GMC cars located in various U. S. cities which were closely inspected for corrosion damage under paint films and chrome surfaces. These studies generally showed the percentage of cars experiencing corrosion was much higher in locations using highway salts, as compared to warm climate locations. One such survey found that 58 percent of cars examined in Detroit had corrosion along chrome moldings, whereas this ratio was only 35 percent in Miami, Florida(4).

Another survey made of 14,000 cars in 44 States indicated where little or no road salts were used, the chrome condition was judged good for 95.6 percent of the cars. In salt application regions, the percentage of cars with good chrome was only 80.4 percent. The chrome trim on cars is especially vulnerable to rusting since it is highly porous, and moisture and oxygen may more readily penetrate the underlying steel. Chrome is less important today, being partially replaced by aluminum(4).

A special corrosion study only recently completed by the American Public Works Association, evaluates the effects of deicing salts and rust inhibitors upon nine Falcon automobiles tested for up to three years in the Minneapolis, Minnesota area(21). Findings show that up to 50 percent of vehicle corrosion can be attributed to deicing salts on streets and highways. Rust inhibitors under controlled use, especially the Carguard product manufactured by Cargill, Inc., are found to reduce corrosion of bright metal parts, but do not provide similar protection for sheet metal parts. The APWA report contains recommendations on need for a) more comprehensive purchase specifications by governmental authorities; b) post-assembly corrosion protection; and c) closer examination of highway deicing procedures(21).

In 1964, various reports(4,104,105) indicated that corrosion of automobile trim systems was increasing due to the greater use of calcium chloride on U.S. highways. Subsequent investigation(4) produced the following findings:

- a. At low humidity, calcium chloride is more severe than sodium chloride in its attack, but there is essentially no difference if the surfaces are continuously wetted.
- b. Stainless steel is more susceptible to attack than other trim systems.
- c. Corrosion can be alleviated by improving exterior trim systems, making salt products more alkaline, and by washing cars frequently during winter(4).

Mufflers, Tailpipes

The short life of automobile mufflers and tailpipes has frequently been cited as a damaging consequence of using highway salts. It has been said that replacement of these underbody parts costs the Nation about \$500 million annually. However, conflicting information has been supplied by one automotive company official stating that muffler and tailpipe deterioration is the result of engine emission acids rather than salts. Likewise, there is diverging opinion as to whether industrial and other air pollution may cause generalized corrosion in automobiles(4, 106).

Rust Inhibitors

The merits of adding rust inhibitors to road salts have not been satisfactorily proved. A committee attached to the Detroit Engineering Society previously concluded the use of inhibitors is of doubtful value in protecting the exterior finish of automobiles. However, certain agents may reduce the weight loss of metals susceptible to corrosion. Comparison studies are open to question but the majority of results do suggest that the car owner benefits little from the use of these inhibitors(4). Canadian researchers have similarly found that the large costs for adding an inhibitor to road salts generally are not justified. The Canadian report concludes these inhibitors slow down, but do not eliminate the corrosion of vehicles caused by highway salts(4).

Other Preventative Measures

The best rust prevention treatment recommended by automotive engineers is frequent car washing. The general literature also advises the car owner that his best protection is frequent washing and periodic waxing. However, more than one reference cites waxes, chrome lacquers and

similarly applied coatings as possibly doing more harm than good because the protective coating may serve to seal in moisture thereby promoting corrosion. Conflicting thoughts likewise are expressed concerning the merits of undercoating, because in time, chipping and peeling of the undercoat occurs. The original car paint, if applied to the underside of the car, may, because of its tighter bond, reduce the corrosion potential compared to undercoating. Regular car washing is relatively effective not only in removing road salts, but also in minimizing dirt, road grime, industrial contaminants, road tars, etc., all of which are detrimental to car finish and appearance(4).

SECTION XIII

EFFECTS ON HIGHWAY STRUCTURES AND PAVEMENTS

Review by Massachusetts Research Council and Findings of U.S. Highway Research Board and Representative States

The 1964 study of the Massachusetts Legislative Research Council(4) gave particular attention to a Symposium of the U.S. Highway Research Board held in 1962, which considered effects of deicing chemicals on highway structures(107). The Board was primarily concerned with bridge floor and deck deterioration in portland cement concrete structures. The Symposium noted that blame for public works damage in question could not be placed solely on deicing agents and that the available data was inconclusive. The evidence did indicate that concrete structure deterioration could be at least partially attributed to inadequate field inspection and failure to follow proper techniques in mixing, transporting, laying and curing the concrete. Air-entrained concrete introduced in the late-1940's and which later gained widespread acceptance, did not meet the fullest expectations unless construction practices were rigidly controlled. It was emphasized that various concrete mixes, even air-entrained concrete, over the first six months do not develop their maximum resistance. If salts are applied over this period of time, there could be significant structure damage. Laboratory studies have also shown that sodium chloride and calcium chloride may have damaging effects on concrete. Defects caused in bridge structures include hairline and larger cracks, splitting or shelling out of the surface layer of the deck, aggregate popouts, scaling, surface pitting, chipping, peeling, progressive deterioration from the edges inward, i.e., raveling, and leaching of the deck, gutters, hub-guards and sidewalks(4,107).

The State of Illinois made its recommendations to the Symposium as follows:

- a) improving the quality of concrete used in structures and pavements;
- b) improving drainage design for better removal of brine and abrasives from bridge surfaces; c) more rigid control over construction practices;
- d) better maintenance; and e) less corrosive ice-removal compounds. On the other hand, the State of Massachusetts did not find that salts were detrimental to bituminous concrete pavements or bridge decks covered with cement concrete(4,107).

Highway departments and others have used various materials and surface treatments in order to protect concrete surfaces from damage by deicing salts. However, experience indicates such measures are usually unnecessary if concrete is properly laid. The U.S. Bureau of Public Roads conducted a series of tests which showed that surface protective coatings are generally of little benefit in minimizing concrete scaling, although in a few cases, certain admixtures are beneficial. The Massachusetts Research Council, in their review of the literature, describes two shortcomings in bridge maintenance which may significantly contribute to concrete damage: a) failure to clear-away chemical-laden accumulations of

snow and ice along gutter and sidewalk sections; and b) failure to remove soil, debris and other obstructions from the gutters, causing poor drainage. Standing salt water can saturate underlying concrete, lowering its resistance to damage, and this water may also seep through construction joints and cracks causing interior damage to the bridge deck(4,107).

Application of deicing salts to concrete roadways in the New York Thruway system have caused few difficulties, but serious problems have been encountered with bridge structures. In order to counteract progressive deterioration of concrete bridge decks, a preventive and corrective maintenance program was established. Additionally, to minimize the effects of salt brine and water passing through bridge expansion joints onto the abutments and piers, the procedures for painting steel members in the structure were modified(4,107).

The report by the State of Kansas to the Symposium gave evidence that highway salting in Kansas is greatly accelerating the scaling of concrete structures. The chlorides also contribute to rusting of reinforcing steel which leads to concrete spalling. Recommendations were given that all decks be sealed with a water repellent material and then carefully covered with a bituminous coating. It was further suggested that steel and timber be waterproofed with paints, asphalts, resins, silicones or equivalent(4,107,108). Similar experiences in Ontario, Canada, however, indicate that asphalt surfacing over concrete tends to trap considerable salt onto the surface of the concrete. The salt solution not only penetrates under the asphalt at the curb zone but also enters into cracks in the asphalt. Excess moisture sealed in by the waterproof coating was considered detrimental to the bridge decking. The Ontario study concludes that adequate drainage must be provided, and no surface coating can adequately overcome defects in design, construction or materials which lead to water and salt being trapped on the bridge decks(4,107).

Comments of Calcium Chloride Institute and Portland Cement Association

A 1961 report by the Calcium Chloride Institute(109) stresses suitable precautions must be taken in using deicing chemicals and that scaling of concrete attributed to salt "is not a chemical attack". The Institute infers that scaling will occur when concrete is less than "ideal". This study emphasizes chemicals should not be used on air-entrained concrete less than 12 months old unless specific measures are followed. For non air-entrained concrete, chemicals should not be applied for at least one year, and in the maximum case, up to four years(4,107). With deicing chemicals, the ability of the chlorides to attract water, and their capability in depressing the freezing temperature of liquids, represent potential hazards to concrete. Salt application will increase the number of freeze-thaw cycles and raise the level of water in the concrete which leads to scaling and spalling. Another study conducted in Massachusetts concludes that highway salts can penetrate the capillaries, particularly in non air-entrained concrete, and cause disruption and scaling of the concrete material at an accelerated rate(4,107).

The Portland Cement Association correlates surface scaling of concrete pavements with the increasing use of sodium chloride and calcium chloride. The severity of scaling is said to depend upon the amount and frequency of salts used. The Portland Cement Association strongly recommends air-entrained concrete where frost action and salt application occur. The Association cautions that concrete pavements may be damaged by heavy salt applications, especially relatively new roadways. Pavements less than four years old are much more vulnerable than older highways. Protective treatments are advised in most cases particularly for concrete pavements less than four years old. Without protective treatment, the Portland Cement Association recommends that heated abrasives be substituted(4,107,110,111). The Massachusetts Legislative Research Council Report specially notes New Jersey provisions, which prohibit the use of salts within 500 feet of a bridge 50 feet or more in length(4).

Other Deicing Compounds

Concerning deicing compounds other than the chlorides, caution was expressed in a concrete industry trade journal as early as 1961, on the corrosiveness of many of these chemicals to concrete. Certain of the agents were found to contain large amounts of ammonium nitrate. These materials are sold under trade names without reference to composition, and also sold in small plastic bags being promoted for sidewalk and driveway use. Unfortunately, the harmful effects of the ammonium compounds and some of the other agents to concrete surfaces, seem to far outweigh their merits in melting ice(4,18,107,112).

Effects on Underground Utilities

Schraufnagel(18), based upon a fact-finding study by Hamman and Mantes(113), describes the corrosive damage of deicing salts upon underground telephone lines and water mains. The Bell and Chicago Telephone Companies previously noticed that corrosive failure of underground cables and transformers was occurring in proximity of highway salting. In Buffalo, New York, the National Association of Corrosion Engineers surveyed the chloride content of manhole waters at 25 locations over a three and one-half year period. Of 175 samples taken in Buffalo, 74 samples had chloride levels in excess of 1,000 mg/l. In Milwaukee, Wisconsin in 1965, the Water Engineering Division, studying the chloride content of groundwaters near buried water mains, found chlorides of 170-225 mg/l near streets routinely salted, compared to 10 mg/l for groundwaters in unsalted areas. Concern was raised as to foreseeable corrosion damage to the water distribution system.

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SECTION XIV

EFFECTS ON SOILS, VEGETATION, TREES

Deicing salts applied to roads and highways are eventually carried by surface runoff into roadside ditches and receiving streams, or these salts will infiltrate into the soils bordering the highway. Through infiltration, deicing salts are carried into groundwaters, remain in soil solution, or are absorbed by soil particles. Soils may be adversely affected as to their fertility and their ability to support desirable plant growth. Because of poor soil conditions, the uptake of salt ions by trees and vegetation, and the toxic properties of these ions, moderate to severe damage is frequently inflicted upon grasses, vegetation, plants, shrubs, bushes and trees. Exposure of plantings is usually most severe in the highway median strip.

This section of the report reviews effects of highway salts upon roadside soils, vegetation, and trees. However, in contrast to previous sections of the report where the literature was relatively sparse, there are numerous reports in this area of study. Keeping in mind the objectives of this report, we have been quite selective in the particular references used for judging effects of salts on soils and plant biota. The materials presented in this section are broadly arranged into discussion of: a) general soil chemistry; b) nature and movement of salts through soils; c) salt uptake by plants and correlative effects; d) salt tolerance of individual species; and e) effects of salt spray on vegetation.

Soil Chemistry, Salt Movement Through Soil Into Plants

Many researchers, particularly those in the western U.S., have studied effects of salts on plants and the occurrence and movement of salts through soils. The problem can be viewed in many ways although total soluble salt content (salinity), and the levels of specific ions are of great importance. Symptoms of injury in plants and trees include advanced coloration of foliage, leaf scorch, defoliation, stunting, and eventually, die-off. Symptoms may however be similar whether due to sodium or chloride, high salinity, or drought conditions. Also, because sodium and chloride salts in themselves give rise to salinity, it is oftentimes difficult to determine the extent of damage caused by each factor(114).

Salinity or total soluble salts cause interference with the mechanism whereby a plant absorbs moisture from the soil. Soil water enters the plant root through a membrane across which an osmotic pressure differential is maintained. The flow of water through the membrane is in the direction of higher salt concentration and therefore, increasing salinity in the soil makes it more difficult for water to be taken in by the plant. The sensitivity of a plant is related to the type of soil present,

the soil "wilting" percent moisture, and amount of salinity per unit weight of soil. Besides short-term damage caused to plants by saline soils, some data show that low salinities over extended periods can cause cumulative damage in due time. In general, other factors being equal, plant growth will be retarded by increased salinity because of increasing salt load or reduced soil water. In similar context, when salinities are raised, more water will be required, to be supplied by rainfall or irrigation, in order to maintain previous plant growth. Leaching of soluble salts from the soils, is inferred as an alternative procedure(114).

The sodium, chloride, and calcium ions are of special significance when deicing salts are used. Chloride per se, is not reported to cause adverse effects on soil characteristics, although it does add to salinity. Chloride ions possess a negative ionic charge the same as that of soil particles. Consequently, chloride ions freely flow through soil particles compared to the cations such as sodium and calcium which are absorbed onto soil particles or precipitated by soil reactions. However, high levels of chlorides do appear as pollutants in groundwater and as toxicants taken in by plants. Excessive chloride accumulates in the leaves causing leaf burn, but also seems to locate in the twigs(52,114).

The sodium ion is important because it not only changes the character of the soil but also exerts a toxic effect on various plants. Cations are absorbed onto soil particles and maintained in equilibrium with cations in the surrounding soil water. If sodium salts are applied to the soil, the equilibrium is changed whereby sodium ions replace calcium ions on the soil grains. With loss of calcium, the soil may become less fertile and also less permeable. High sodium levels can cause dispersion of colloidal soil particles, which eventually leads to alkali soils characterized by lack of aggregation and structure, and poor drainage properties. Sodium is often considered toxic to trees and other plants with translocation to the leaves and twigs causing burning and browning. Although thought to be generally non-essential to plant growth, sodium can interfere with uptake of potassium, an essential plant element, and even serve in its place(114,115).

Calcium is a commonly found element in soils and appears essential for plant growth. Calcium may be added to soil as lime or gypsum to replace undesirable sodium ions and restore soil fertility. However, excessive calcium can cause high salinity and may be specifically toxic(114).

The 1963-1964 winter season was the first time the National Capital Region of the National Park Service authorized the use of sodium chloride on Park roads in the Washington, D.C. metropolitan area. Various research included microscopic examination of Kentucky bluegrass leaves and roots, and observations of damage to vegetation and trees along approximately 70 miles of Park roads. Although this study conducted in 1964 did not reveal detectable injury to plant biota, the results provided comparative background for significant salt damage

experienced the following winters. In his early 1964 studies, Thomas(116) found the most important factors associated with sodium chloride injury were:

- 1) Amount of salt applied
- 2) Amount of salt reaching vegetation, and retained and absorbed by the plants
- 3) Availability of water
- 4) Temperatures during plant growth
- 5) Wind velocities
- 6) Soil characteristics
- 7) Dormancy of plants and onset of plant growth
- 8) Plant tolerances and individual species sensitivities
- 9) Cumulative or long-term effects of salt

Salts reaching vegetation are reduced where curbing and storm sewers are established. Available rains may leach out excessive salts from soils but Thomas from his review(116) indicates this rainfall in humid regions must do more than merely saturate the soil in order to produce adequate salt leaching. Light rains appear to have little effect. Sodium chloride, total soluble salts, particular soil types, and shallow plants and soils will serve to intensify "drought" conditions. It had been previously recommended that total soluble salts in soils be maintained below 100 ppm, but as early as 1964, soluble salts adjacent to salted parkways were already in the range of 1,860-2,580 ppm (1 ppm = 1 µg/g or 1 mg salt/kg soil). It is extremely advantageous if salts can be leached from the soils before active plant growth starts in the spring. For this reason, a late salt application around the beginning of March may be much more harmful than a heavy mid-winter application.

Thomas(116), based upon his review, also points out that damaging effects of salts may not become apparent for several years, that sub-lethal salt doses may cause plants to become more generally susceptible to disease, and that salt changes in soils and vegetation may more subtly, but more importantly, be affecting entire natural ecosystems.

Prior and Berthouex(16,114) studied the movement and accumulation in roadside soils of highway salts applied by the Connecticut State Highway Department. Soils were sampled at the surface, one, two and three foot depths, and at distances 5, 25, 50 and 100 feet from the highway. Soil samples were analyzed for total soluble salts, chlorides and sodium. Greatest salt concentrations were found near the highway and close to the soil surface, as anticipated. In a number of cases, salt was shown as travelling more than 100 feet laterally from the highway, but the predominant movement was downward. Total soluble salts, sodium, and to a lesser degree, chlorides, were significantly higher within the soils in January-February compared to the other months of the year. This seasonal difference was also noted in the soils 100 feet from the highway. Salts were readily leached from the upper several feet of soil and by April the majority of salts were displaced downward. Salt concentrations were reduced to minimal levels through the summer and fall before salt

applications were due to be resumed the following winter. Since all data were collected in one year, no estimate is possible of salt accumulations in successive years(114).

Wintertime Infiltration

The question of how much infiltration occurs in the wintertime is quite important in predicting the portion of highway salt loads contained in highway drainage vs. that entering the soil horizon. The majority of the literature tends to indicate that infiltration will occur throughout the year except when the ground is frozen. During the winter, we may therefore expect little or no infiltration, and snowmelt would largely take the form of surface runoff. However, observations in Massachusetts and other locations indicate this may not be the case. In the Boston area, long-term studies have shown that infiltration and groundwater recharge continue throughout the winter although at slower rates(19). Prior(114) in Connecticut, found almost normal infiltration occurring in forest soils frozen to a depth of 4 inches. Light textured soils allow for greater infiltration during times of freeze. Prior indicates even with frozen ground conditions, at least some water and salt will infiltrate into the roadside soils.

Salt Levels in Roadside Soils Along Maine Highways

Hutchinson extensively studied sodium and chloride levels in soils adjacent to salted highways in Maine from mid-1965 through 1969. Hutchinson selected his sampling sites on the Maine Turnpike and Interstate 95. Soils were collected at 6 and 18-inch depths, and in 5-foot increments from the edge of the road up to a distance of 45 feet. A minimum of 12 borings was composited for each sample. Sampling sites were also established along a number of other major highways in the State. In this second series, samples were secured at discrete distances of 0, 30 and 60-feet from the road embankment(115,117).

Different sections of Interstate 95 were opened in various years, and Hutchinson was able to correlate sodium and chloride levels with the number of years these roadside soils had received deicing salts. One section of roadway after a single winter demonstrated a five-fold increase in sodium at the 6-inch soil depth near the edge of the highway. Increases in sodium were shown at the 6-inch depth up to 30 feet from the highway. At the 18-inch soil depth, this increase was evident over 10 feet lateral distance. Background sodium values were generally 30-40 ppm ($\mu\text{g/g}$), compared to a maximum value of 235 ppm sodium found after the one winter of salting. Chloride background values were all recorded as trace amounts. After salting, chlorides at the 6-inch soil depth varied from 30-174 ppm over the 45 feet of lateral distance. At the 18-inch soil depth, chlorides ranged from 38-107 ppm(115,117).

Four other sites on the Maine Turnpike and Interstate 95, which had received yearly salting for 2,3,5 and 18 years, respectively, were also sampled. All soils in this study series were derived from marine sediments adding uniformity to the results obtained. Compared to background, the sites salted for 2 and 3 years, showed sodium increases in the 6-inch deep soils of 4 to 8 fold near the edge of the highway. Sodium content was significantly high at both the 6 and 18-inch soil depths extending outward some 30-35 feet from the highway.

The section of highway receiving salting over 18 winters indicated very high sodium levels in the soils directly adjacent to the road. High sodium content prevailed over the entire 45 foot lateral distance sampled. Compared to the background levels of 30-40 ppm, the sodium content averaged 333 ppm for all soil samples taken at the 6-inch depth; the maximum value was 488 ppm for surface soils 5 feet from the highway. For all samples at the 18-inch depth, the average sodium content was 218 ppm, with a maximum value of 307 ppm for the soils 5 feet off the roadway(115,117).

Chloride levels for the above four highway sites showed the same soil relationships as sodium but quantitative results were lower since chloride moves more rapidly through the soils. With trace amounts of chloride serving as background, the sites receiving 2 and 3 winters of highway salting exhibited 46-100 ppm chlorides in the surface soils next to the road, diminishing to 12-24 ppm in the surface soils 45 feet from the road. The site with 18 winters of salting had 183-217 ppm chlorides in the surface soils 5-15 feet from the roadway diminishing to 115-117 ppm in the outer periphery(115,117).

At other highway sites in the State of Maine sampled by Hutchinson, (a total of 22 locations), the levels of salt ions in surface soils exhibited wide variation, with sodium ranging from 14 to 1,056 ppm and chlorides ranging from 8 to 768 ppm. The various roadside soils across the State, on the basis of being collected 0, 30, and 60 feet from the highway, showed respective average sodium values of 281, 139 and 96 ppm. Associated chloride values were respectively 116, 79, and 54 ppm. Sodium and chloride content of soils immediately adjacent to the highways were 6 and 115 times higher than are normal for soils in the State of Maine. Considering the width of highway right-of-ways, it was concluded that private properties and soils were very much being affected by highway salting(46,89,117).

At one roadside location where the soils were examined in greater detail, Hutchinson found that the cation exchange capacity of the Buxton soil series present at this particular site was 23 percent saturated with sodium cations. In the western U.S., soils having a sodium saturation greater than 15 percent are designated as "alkali" soils. A number of roadside soils in Maine may likewise be placed in this "undesirable" classification. In summarizing Hutchinson's findings, it is seen that levels of both sodium and chloride ions in the soils along major highways in Maine have increased markedly as a result of highway deicing. It is

clearly demonstrated that deicing ions have moved laterally at least 60 feet and downward at least 18 inches with time over which these roadways were salted. A strong correlation was shown between the consecutive number of years of salting at a given location vs. the increasing levels of sodium and chloride ions in adjacent roadside soils. The carry-over and accumulation of salts within the soils from one year to the next was strongly suggested. Hutchinson also expresses the need to study soil treatment measures using compounds such as calcium sulfate and calcium carbonate in flushing excessive sodium from damaged soils. These soil treatments may be required only once every two or so years(46,89,115,117).

Chloride Content of Soils and Plants on National Park Grounds, Washington, D.C.; Correlation with Plant Injury and Death

In continuation of the study on effects of salts on National Park lands in Washington, D.C. during 1964, ensuing investigations were carried out by Thomas and Bean in 1965(118), and Wester and Cohen in 1967(119). Thomas(120) also reports upon a qualitative analytical method used to determine "excessive" or "normal" amounts of chloride present in soils and the roots of Kentucky bluegrass receiving highway salts. In March 1965, extensive die-off of bluegrass sod was noted next to sidewalks and roads in National Arlington Cemetery and within the parking lot of the National Capital Regional Office Building. In March-June 1965, samples were collected of soils and plant roots for chloride analyses from the salt-affected areas, and also from various parkways in and around Washington, D.C. Control samples were taken in areas not receiving salts. The study attempted to correlate the "vigor" of vegetation with the presence of chlorides. Unhealthy conditions included observation of dead, chlorotic or stunted plants.

Thomas and Bean(118) found the time of the year at which tests are conducted to be quite important. For example, salt could kill the plant, be leached out of the area, and not suspected or proved later as the cause of death. On the other hand, with adequate salt leaching there could be subsequent plant recovery. Also, salt uptake by the plant could cause it to be slightly chlorotic, but it is not certain when and if these plants would show significant damage. However, another winter of salting would likely aggravate this condition. Although observed damage was confined mostly to areas proximate to road shoulders and walkways, excessive chlorides were found in soils 20 feet from the edge of the road. Good correlations were established between the state of health of bluegrass vs. ppm soluble salts in soils (break point of 843 ppm); and between excessive chlorides in soils vs. ppm soluble salts in soils. Qualitative (excessive) soil chlorides were considered a more reliable indicator of salt injury and loss of plant vigor than the measurement of chlorides in plant roots. The authors conclude with the increasing use of salts in the Washington, D.C. area, that decline and death of vegetation will continue(118).

Following the relatively severe winter of 1966-1967 in the Washington, D.C. area during which 37 inches of snowfall occurred, Wester and Cohen(119) found severe salt damage to vegetation. The effects of heavy wintertime salting were compounded by a serious lack of rainfall in April, 1967 which provided little opportunity for natural leaching of salts from the root zone. Observed and recorded plant damage was most prevalent in Kentucky bluegrass, California privet, Canadian hemlock, sugar maple, American elm and Quebec linden. Samples were taken for qualitative levels of chlorides in plant leaves and quantitative levels of chlorides in soils. Both affected and non-affected areas were sampled for comparative results. Much of the damage was associated with accumulations of salts previously deposited by snowplows and front-end loaders. Chloride concentrations of soils in non-salted areas varied from 0.000 to 0.001 percent, compared to levels of 0.01 to 0.09 percent for salted areas (note 0.01 percent = 100 ppm, and 0.1 percent = 1,000 ppm). The high chloride content of 0.09 percent was derived from roadside soils underlying a privet hedge in Fort Myer, Virginia in August 1967, where almost all plants were killed.

At the Walter A. Reed Army Medical Center in Washington, D.C., severe damage in 1967 was caused to a section of Canadian hemlock adjacent to a parking lot and to street-side plantings of sugar maples. There was also some damage to turf caused by runoff from uphill salted areas. The maples showed symptoms of stunted growth, marginal leaf scorch, foliage thinning, pre-season defoliation, sun-scald of bark and leaders because of undue tree exposure, and eventual die-off. Wester and Cohen(119) classified their observations on plant damage into three categories: moderate damage, severe damage, and complete kill. There were no plants within the non-salted areas falling into any of these categories. However, the vegetation on salted land areas, depending upon the site, was rated from 0-100 percent in each category. The authors comment that any salt damage may greatly shorten the life of affected trees; and shrubbery and turf can be killed in a single season. They suggest that salted snow should be kept within street curbs rather than placed in proximity to plants and vegetation. Furthermore, potentially-affected areas should be heavily watered in the early spring if at all possible(119).

Sodium and Chloride Content of Grasses, Salt Tolerances

Along Interstate 80 in Johnson County, Iowa, unsuccessful attempts were made in 1964 and 1965 to establish turf in the roadside areas. Salt contamination was considered the major cause preventing establishment of seedlings. Studies by Roberts and Zybur(103,121) were designed to evaluate salt tolerance and suitability of various coarse texture grasses for roadside use in Iowa. Soluble salt determinations in soil samples indicated salt levels sufficiently high to reduce grass growth up to 10 feet from the road. Greenhouse pot and field plot tests showed salt tolerance was greatest for Kentucky 31 fescue, decreasing through slender wheatgrass, intermediate wheatgrass, western wheatgrass, followed by other varieties. The grasses exhibited increased foliar growth at

sodium chloride levels up to 631 ppm, but it was noted that soil dispersal and deflocculation occurred at the 1,262 ppm salt level; and above 1,000 ppm, injury to grasses became more evident. Unfortunately, long-term effects of moderate salt levels on grasses were not determined. Of all grasses tested, Kentucky 31 fescue not only had good sod and root development, but also showed best physiological and overall growth when used in a salted roadside environment.

Verghese et. al., (122) conducted several tests both in the field and the greenhouse to determine effects of deicing salts on various grasses used along highways. They found a close relationship between rates of salt applications and the amounts of sodium and chloride ions in roadside grasses. Chloride accumulations within grasses were several times higher than sodium. Salt applications decreased the yield of all grasses studied. Of the various grasses, Kentucky 31 fescue showed good adaption to reasonably high salt levels. Nitrogen soil treatments seemed to counteract decreasing grass yields due to sodium chloride, but nitrogen also tends to increase the uptake rate of sodium and chloride in tissues. Other results indicate that potassium phosphate may be effective in reducing salt injury to grasses, but phosphate stimulates plant growth providing more surface area for salt absorption. Other soil improvement measures include addition of soluble calcium salts, gypsum, or anhydrous ammonia to the soil (5,46,117,123,124). Gypsum is reported to be an effective and inexpensive amendment for saline soils.

Salt Injury to Trees, St. Paul, Minnesota

French in the late 1950's (5,125), observed salt-injury symptoms of American elm and other species of trees along various city streets in St. Paul, Minnesota, following winters of heavy road salting. Tree leaves turned yellow, then brown, generally coinciding with the start of hot dry weather and this phenomena became more pronounced through the summer. French noticed that tree defoliation and serious injury were more prominent on the side of the tree fronting the street. Although soluble salts in the soils appeared to be below the danger level, injured parts were shown to contain abnormal levels of sodium. These findings were duplicated in greenhouse experiments when sodium chloride - calcium chloride mixtures were applied to American elm seedlings.

Sodium and Chloride Levels in Sugar Maples and Silver Maples in New Hampshire, Massachusetts, Vermont and Connecticut; Correlation with Injury and Death

Rich and LaCasse from various studies in New Hampshire determined that sugar maples and other trees along a heavily-travelled and heavily-salted highway were moderately to severely injured. Trees within 30 feet of the highway were usually injured, whereas trees greater than

30 feet away were almost always healthy. Symptoms included leaf scorch, early coloration and defoliation, reduced growth, browning of twigs and branches, and eventual die-off of severely-affected trees. Injury could not be correlated with size or age of tree, soil type, fertility, or prevalence of parasites. Foliage from affected trees showed abnormally high sodium content and the sap from injured trees was high in soluble salts. Later studies in New Hampshire showed that maple trees along salted State roads displayed considerable injury, whereas almost no injury was observed for similar trees along unsalted town roads in the same general area. These investigations found that chloride content was a somewhat better indicator than sodium for determining damage to foliage, but in tree sap, sodium was the better indicator. For the healthy, moderate, and severe injury classes, sodium levels in foliage were respectively, 0.02, 0.03 and 0.17 percent. Chloride levels were higher showing 0.06, 0.28 and 0.42 percent, respectively(126,127,128,129).

Rich and LaCasse(128) have repeatedly found of the various deciduous trees, that maples are most prone to injury and damage caused by highway salts. Kotheimer et. al.,(5,130) conducted studies in New Hampshire of maple trees receiving highway salts compared to similar trees receiving little or no salt. Sugar maples were seen to be more susceptible to highway salts than the red maples. Kotheimer concluded that road salt application was definitely associated with less vigorous and deteriorating maples alongside New Hampshire highways. Westing(5,131) in his review of sugar maple decline, notes that many causes may be responsible for this decline including adverse environmental conditions, disease, or completed life cycle. Salt may only be one of these causes, albeit an important one. Westing mentions symptoms such as reduced growth, loss of coloration, marginal necrosis in leaves, twig and branch die-off, and premature leaf loss. Sixteen States in the northeast and north-central U.S. have become concerned with this problem, but the sugar maple decline has been particularly prevalent in the State of New Hampshire.

Additional studies have been undertaken by Holmes and Baker(132) on sugar maple decline in Massachusetts, and by Zelazny et. al.,(133) on silver maple decline in Vermont. Following extensive investigations from 1961-1964, Holmes and Baker concluded that foliar chloride levels in sugar maples could be correlated with injury levels, and salt does injure and even kills sugar maple trees. Holmes and Baker take the position that roads must be kept safe in the winter. However, care should be taken to minimize damage to maples by judicious use of a salt in sand mixture applied after plowing. They make it equally clear that more lavish use of salt will increase both foliar chloride uptake and injury to sugar maples. Salts may also affect the vulnerability of trees to other injuries or disease, and these other agents may affect the intensity of salt injury. Holmes and Baker observed minimal or no injury symptoms in the range of 0.05 to 0.6 percent foliar chlorides (1 to 12 times normal); slight or moderate symptoms were present in the range of 0.4 to 1.0 percent foliar chlorides; and severe symptoms were experienced above 1.0 percent chlorides. It was moreover concluded that foliar symptoms when correlated with chloride levels in excess of 0.3 percent

should not be attributed to factors other than salt. Regarding foliar sodium levels, these were shown to be much lower than chlorides. Trees with severe injury had foliar sodium from 0.004 to 0.053 percent; and those with less severe symptoms had 0.0006 to 0.084 percent sodium(132).

Zelazny et. al.,(133) undertook studies in an area of extensive silver maple decline in Vermont attributed to highway salts. Heavy salt applications reached roadside soils and were consequently absorbed into the leaves and stems of nearby trees. Chloride toxicity was judged more critical than total soluble salts. The test results indicated that chloride levels of 0.20 percent in the leaves produced leaf scorch, whereas chloride percentages in excess of 0.50 percent were correlated with leaf scorch, defoliation and ultimate plant death. Sodium levels were much higher in damaged trees compared to healthy trees (respectively, 0.005 - 0.146 percent vs. 0.002 - 0.016 percent in the leaves), and thought to be one of the possible reasons for overall plant deterioration. The authors recommend that woody vegetation should be located as far from the highway as possible, that plants be selected on the basis of salt tolerance, and the highway drainage be diverted away from roadside vegetation(133).

Unpublished work by Button and Peaslee reported in the 1970 Highway Research Board literature review(5,134), indicates that high levels of sodium and chloride may be expected in trees exposed to highway drainage. Observed symptoms included leaf-burn injury, decline in vigor, and defoliation. The leaves of sugar maple trees showing margin burns contained around 5,000 ppm chlorides, and trees near die-off had around 9,000 ppm chlorides. Low levels of highway salts applied over a sufficiently long period of time could accumulate within the plant causing serious injury and plant death. The range of chlorides within the leaves of damaged trees was 0.26 to 0.94 percent. For healthy trees these levels were 0.03 to 0.31 percent(5,135,136,137).

Allison from his observations on various species of plants, indicated in 1964 that chloride accumulations around 1-2 percent (i.e., 10,000-20,000 ppm) would cause marginal burn, leaf drop, twig dieback, and death of the plant. These chloride accumulations will occur when chlorides in soils are in the approximate range of 700 to 1,500 ppm. Sodium content of 0.05 percent or even less, also produces leaf burn and significant plant injury(5,138).

Salt Tolerance of Individual Plant Species; Fruit, Vegetable and Field Crops, Grasses, Trees and Ornamentals

The subject of salt tolerance and variability between plant species is a most interesting one. Salt tolerance of various plants has been studied and classed with respect to: 1) relative plant yield on saline soils compared to non-saline soils; 2) plant yield on saline soils; and 3) the ability of the plant to survive on saline soils. The majority of the information developed on salt tolerance is based upon the first

and second criteria given above. This is because most research on salt tolerance has been carried out in the arid and semi-arid regions of the U.S., and within these areas crop yields have been of high importance. Keeping in mind the third criteria is probably of greatest interest to highway personnel, that is the ability of the crop to survive in saline soils, information on salt tolerance can nevertheless be used as a useful guideline in selecting roadside plants and vegetation. The data presented in Tables V through IX below would appear to represent some of the best and most concise information available. Tables V, VI, VII, and VIII respectively, give the salt tolerance of various fruit crops, vegetable crops, field crops, and grasses. These tables are taken from the 1970 Highway Research Board literature review(5) but the original source material is found in previous publications of the U.S. Department of Agriculture. Table IX gives the salt tolerance of trees and ornamentals taken from Zelazny, 1968(139). Each table gives major plant or major crop arranged according to whether the plant is salt tolerant; moderately tolerant/sensitive; or sensitive. Within each class, the plants are listed in decreasing order of salt tolerance; however, differences of 2 or 3 places in the columns may not be significant. The discussion following gives further information on the salt tolerance of ornamental shrubs and trees which is of particular interest to this report.

Various researchers have studied the salt tolerance of ornamental trees and shrubs. Monk and Peterson(5,144) using one-year old seedlings, classify 20 different species as follows: 1) Most Salt Tolerant - black locust, honey locust, Russian olive, squaw bush, and tamarix; 2) Salt Tolerant - Silvery buffalo berry, golden willow, ponderosa pine, and green ash; 3) Moderately Tolerant - Japanese honeysuckle and eastern red cedar; 4) Least Tolerant - Blue spruce, Douglas fir, black walnut, little-leaf linden, barberry, winged euonymus, multiflora rose, spiraea, and arctic blue willow.

Rudolfs(5,145) finds that oak has greatest salt tolerance, birch has intermediate tolerance, and maple is most sensitive. Zhemchuzhnikov(139) concludes that trees with greatest salt tolerance are light-loving species with a fair degree of drought resistance and usually located in arid climates. Hanes, et. al.,(5) also point out that vegetation not subject to annual harvesting could, over time, accumulate sufficient salt within the plants to cause serious damage. This effect is important when considering the tolerance of perennial woody plants. Zelazny(139), based upon an extensive literature review, has classified the salt tolerance of 67 various trees and ornamentals as shown in Table IX.

We have previously described the three criteria determining the type of salt tolerance data and plant classifications generally available. Zelazny(139) with reference to these criteria does not believe high yields are necessary, or even desired in some cases, for highway vegetation. Rather it is desirable that roadside vegetation be maintained the year around with minimum effort and cost, erosion be prevented, and the roadside environment be aesthetically attractive. Since the majority of

salt tolerance data were developed in the arid U.S., we should compare climate conditions of the western U.S. with that existing in the highway salting regions of the northeast and north-central U.S. Zelazny(139) finds that arid and semi-arid areas usually experience high salt levels and water shortage. In the northeast and north-central States, the climate is cooler and more humid, implying that toxicity of specific salt ions is more important than water shortage. Vegetation in the western U.S. has also been exposed to saline conditions for thousands of years which undoubtedly has created a natural selection of plants to salt tolerance. Such a selection has not occurred to as high a degree in the eastern U.S. It appears ironical that many plants capable of tolerating high salt concentrations in the West are not able to withstand the cool, moist climate in the East(139). Conversely, plants and vegetation in the highway salting regions of the U.S. lacking this natural selection, would appear to be significantly more sensitive to salt injury.

Effects of Salt Spray on Vegetation and Roadside Environment

Two separate studies have described the effects of salt spray on vegetation alongside highways. Where calcium chloride was sprayed on roads to reduce dust, Strong(5,146) found there was frequent injury to roadside trees particularly leaf scorch, and at times even tree die away. With small concentrations of calcium chloride, symptoms of leaf scorch and needle burn could not be readily ascribed to salting as distinguished from drought. However, higher levels of calcium chloride produced more rapid injury. Direct application of calcium chloride and dust mixtures to leaves did not appear to cause symptoms of leaf scorch, but rather produced a brown spotting of the leaves. Sauer(5,147) believes that salt spray from highways may often be the major cause of roadside plant injury rather than salt being absorbed from the soil. Sauer observed that certain portions of roadside plants which were directly behind snow or beam barriers and thereby protected from the spray, were consequently spared salt injury.

Following heavy snowstorms, motorists frequently perceive a salty atmosphere prevailing along the highway. This haze of airborne crystals and dissolved salt stirred up by vehicular traffic will tenaciously adhere to automobile windshields, increasing the opportunity for traffic accidents. A much higher potential also exists for accelerated corrosion of automobile finish and metal parts. It was estimated in Milwaukee County, Wisconsin, that up to 10 percent of the highway salt on any one day may become airborne, which could represent nearly 25 percent of the total air pollution load normally prevailing in that County(26,60).

TABLE V
SALT TOLERANCE OF FRUIT CROPS^{1/}

<u>Tolerant</u>	<u>Moderately Tolerant</u>	<u>Sensitive</u>
Date palm	Pomegranate Fig Olive Grape Cantaloup	Pear Apple Orange Grapefruit Prune Plum Almond Apricot Peach Strawberry Lemon Avacado

1/ Original Source, Bernstein, L., 1965(140)

TABLE VI
SALT TOLERANCE OF VEGETABLE CROPS^{2/}

<u>Tolerant</u>	<u>Moderately Tolerant</u>	<u>Sensitive</u>
Garden beet Kale Asparagus Spinach	Tomato Broccoli Cabbage Cauliflower Lettuce Sweet corn Potato Sweet potato-yam Bell pepper Carrot Onion Pea Squash Cucumber	Radish Celery Green bean

2/ Original Source, Bernstein, L., 1959(141)

TABLE VII
SALT TOLERANCE OF FIELD CROPS^{3/}

<u>Tolerant</u>	<u>Moderately Tolerant</u>	<u>Sensitive</u>
Barley	Rye	Field bean
Sugar beet	Wheat	
Rape	Oats	
Cotton	Sorghum	
	Sorgo (sugar)	
	Soybean	
	Sesbania	
	Broadbean	
	Corn	
	Rice	
	Flax	
	Sunflower	
	Castorbean	

^{3/} Original Source, Bernstein, L., 1960(142)

TABLE VIII
SALT TOLERANCE OF GRASSES AND FORAGE LEGUMES^{4/}

<u>Tolerant</u>	<u>Moderately Tolerant</u>	<u>Sensitive</u>
Alkali sacaton	White sweet clover	White dutch clover
Saltgrass	Yellow sweet clover	Meadow foxtail
Nuttall alkali-grass	Perennial ryegrass	Alsike clover
Bermuda grass	Mountain brome	Red clover
Tall wheatgrass	Harding grass	Ladino clover
Rhodes grass	Beardless wildrye	Burnet
Rescue grass	Strawberry clover	
Canada wildrye	Dallis grass	
Western wheatgrass	Sudan grass	
Tall fescue	Hubam clover	
Barley	Alfalfa	
Birdsfoot trefoil	Rye	
	Wheat	
	Oats	
	Orchard grass	
	Blue gamma	
	Meadow fescue	
	Reed canary	
	Big trefoil	
	Smooth brome	
	Tall meadow oatgrass	
	Milkvetch	
	Sourclover	

^{4/} Original Source, Bernstein, L., 1958(143)

TABLE IX
SALT TOLERANCE OF TREES AND ORNAMENTALS^{5/}

<u>Tolerant</u>	<u>Moderately Tolerant</u>	<u>Poorly Tolerant</u>
Common matrimony vine	Silver buffalo berry	Black walnut
Oleander	Arbor vitae	Little leaf linden
Bottlebrush	Spreading juniper	Barberry
White acacia	Lantana	Winged euonymus
English oak	Golden willow	Multiflora rose
Silver poplar	Ponderosa pine	Spiraea
Gray poplar	Green ash	Arctic blue willow
Black locust	Eastern red cedar	Viburnum
Honey locust	Japanese honey suckle	Pineapple guava
Osier willow	Boxelder maple	Rose
White poplar	Siberian crab	European hornbeam
Scotch elm	European black currant	European beech
Russian olive	Pyracantha	Italian poplar
Squaw bush	Pittosporum	Black alder
Tamarix	Xylosma	Larch
Hawthorne	Texas privet	Sycamore maple
Red oak	Blue spruce	Speckled alder
White oak	Douglas fir	Lombardy poplar
Apricot	Balsam fir	Red maple
Mulberry	White spruce	Sugar maple
	Beech	Compact boxwood
	Hard maple	Filbert
	Cotton wood	
	Aspen	
	Birch	

^{5/} From Zelazny, L., 1968(139)

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SECTION XV

SUMMARY

Current annual use of highway deicing compounds in the U.S. is estimated around nine million tons of sodium chloride, one-third million tons of calcium chloride, and eight million tons of abrasives. About 40 States, mostly in the northeast and north-central U.S., employ highway deicers. "Bare-pavement" conditions for streets and highways in the wintertime are considered necessary to adequately protect the lives and safety of motorists using these roads. The use of sodium chloride and calcium chloride as deicers has increased rapidly over the past 15 years. The leading States in total use of highway salts are Pennsylvania, Ohio, New York, Michigan and Minnesota.

Highway salting rates are usually in the range of 400 to 1,200 pounds of salt per mile of roadway per application, and many roads and highways in the U.S. may receive more than 20 tons salt per lane mile or more than 100 tons per road mile over the winter season. Snow-control equipment includes tail-gate and hopper-type spreaders, trucks, front-end loaders, snow blowers, plows, thermal melting systems, etc. Considerable wasting of highway deicing salts occurs because of excessive application, misdirected spreading and general wintertime difficulties.

Salt storage is necessary for sustaining highway deicing operations, but these facilities too frequently become a major contributing source of groundwater and surface water salt contamination. Salts are stored unprotected in open areas, or placed in unused buildings, garages, sheds, cribs, storage bins and upon elevated platforms or pallets. Because of water supply contamination and desirability of better product handling, many communities have turned to covering of salt piles, enclosed structures, and diversion and collection of salt-laden drainage.

Street runoff from the melting of ice and snow mixed with chloride salts, finds its way via combined sewers to the local sewage treatment plant, and via storm sewers to nearby receiving streams. Daily chloride loads were shown to be 40 to 50 percent higher for winter months as compared to summer months in municipal sewage at Milwaukee, Wisconsin. During days of heavy snow-melt, daily chloride loads were three-fold the normal summertime loads.

Runoff samples collected from a downtown Chicago expressway in the winter of 1967 showed chloride content from 11,000 to 25,000 mg/l. It has been calculated that 600 lb. salt when applied to a one-mile section of roadway 20 feet wide containing 0.2 inches of ice, will produce an initial salt solution of 69,000 to 200,000 mg/l in the temperature range of 10°F - 25°F. At Milwaukee on January 16, 1969, extremely high chloride levels of 1,510 to 2,730 mg/l were found in the Milwaukee, Menomonee and Kinnickinnic Rivers, believed directly attributable to deicing salts entering these streams via snow melt. The dumping of extremely large amounts

of accumulated snow and ice from streets and highways, either directly or indirectly into nearby water bodies, could constitute a serious pollution problem. These deposits have been shown to contain up to 10,000 mg/l sodium chloride, 100 mg/l oils, and 100 mg/l lead.

A 1966-1968 survey of twenty-seven farm ponds along various highways in the State of Maine showed that road salts have strong seasonal influence on the chloride level of these waters, and that salt concentrations were increasing yearly. Density stratification of chlorides was observed in Beaver Dam Lake at Cumberland, Wisconsin, in First Sister Lake near Ann Arbor, Michigan, and Irondequoit Bay at Rochester, New York, all three cases attributed to salt runoff from nearby streets entering these lakes. Highway salts are also estimated to contribute 11 percent of the total input of waste chlorides entering Lake Erie annually. Sodium from road salts entering streams and lakes may additionally serve to increase existing levels of one of the monovalent ions essential for optimum growth of blue-green algae, thereby stimulating nuisance algal blooms.

Special additives are present within most highway deicers sold today and may create pollution problems more severe than caused by the chloride salts. Ferric ferrocyanide and sodium ferrocyanide are commonly used to minimize caking of salt stocks. Sodium ferrocyanide is quite soluble in water and will generate cyanide in sunlight. Tests by the State of Wisconsin showed that a 15.5 mg/l solution of sodium ferrocyanide produced 3.8 mg/l cyanide after 30 minutes. Levels of cyanide toxic to fishlife range downward to 0.1 mg/l, but desired levels are sought as low as 0.01 mg/l. Maximum and desired levels of cyanide in public water supplies range from 0.2 to 0.01 mg/l.

Chromate and phosphate additives have been used in highway deicers as corrosion inhibitors. As with cyanide, chromium is quite toxic, and limits permitted in drinking water and other waters are quite low. The maximum amount of hexavalent chromium allowed in public water supplies is 0.05 mg/l. In the Minneapolis-St. Paul area, during the winter of 1965-1966, snow melt collections showed maximum values of 24 mg/l sodium chromate, 1.7 mg/l hexavalent chromium, and 3.9 mg/l total chromium.

Serious groundwater pollution has occurred in a number of locations, due to heavy amounts of deicing salts applied onto highways and inadequate protection given to salt storage areas. The State of New Hampshire, up to 1965, is reported to have replaced more than 200 roadside wells at a total cost of more than \$200,000, because these waters had been contaminated by highway salts. Some of the wells exhibited chlorides in excess of 3,500 mg/l. In Manistee County, Michigan, a roadside well located 300 feet from a highway department salt storage pile, was found to contain 4,400 mg/l chlorides.

Tastes and odors in a municipal water supply in Connecticut were ascribed to sodium ferrocyanide originating from a salt storage pile. Also in Connecticut, a salt storage area was responsible for contaminating the well water supply serving four families. Within Massachusetts, salt

increases have been noted in the water supplies of some 63 communities, at least in part due to road salting and salt storage piles, and certain water supplies have been abandoned.

Road salts not only promote vehicular corrosion, but additionally may affect structural steel, house sidings, buildings and other property alongside the highway. It has been estimated that the private car owner pays for corrosion in the amount of about \$100 per year. Frequent car washing is still generally recommended as the best protection possible.

Deicers may cause appreciable damage to highway structures and pavements. Concrete pavements and bridge floors and decks constructed of Portland cement concrete show greatest susceptibility to salt attack. Air-entrained concrete is reported superior to non air-entrained concrete in its resistance to salts. Nevertheless, deicing chemicals should not generally be applied even to air-entrained concrete for at least one year, after it is poured.

Significant damage of roadside soils, vegetation and trees has been caused by liberal application of highway salts. Symptoms of injury in plants and trees include leaf scorch, defoliation, stunting, and ultimately, plant die-off. Soil damage includes loss of fertility and permeability, and dispersion of soil colloids, resulting in lack of aggregation and poor internal drainage. Many of the studies dealing with salt injury and death of roadside trees have focused on sugar maple decline which is occurring over a 16-State area, but mostly in the New England States. Foliar (leaf) chloride levels in sugar maples have been correlated with extent of injury, when in excess of 0.3 percent chlorides.

Included in this report are a series of tables giving relative salt tolerance of various fruit crops, vegetable crops, field crops, grasses, forage legumes, trees and ornamentals. These data, are intended to serve as approximate guidelines for highway authorities and others in selecting roadside plants and vegetation. It is believed that plants of the northeast and north-central U.S. may be inherently more sensitive to salt injury than has been previously thought.

SECTION XVI

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SECTION XVII

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